The Machines of Francesco Di Giorgio:
Demonstrations of the World

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Thesis Abstract

This thesis is an exploration of the chapters of Francesco Di Giorgio's *Trattati di Architettura, Ingegneria e Arte Militare,* that pertain to mechanical devices. While it is difficult to imagine actually constructing Di Giorgio's machines from the drawings and descriptions in his treatises, given their apparent inefficiencies and ambiguities, the Aristotelean science and philosophy referenced throughout the *Trattati* provides a basis for looking at them as demonstrations of concepts beyond their immediate applications for architecture and engineering. By considering these devices in Di Giorgio's own terms, terms suggested by his own experiences, as well as his writings and paintings, strong associations can be made to the science, philosophy and the theology of his time.

Résumé

Cette thèse est une exploration des chapitres du *Trattati di Architettura, Ingegneria e Arte Militare* de Francesco Di Giorgio, qui se rapportent aux appareils mécaniques. Quoique qu'il est en fait difficile d'imaginer la construction d'un engin de Di Giorgio d'après les dessins et les descriptions de ses traités, étant donné leurs inefficacité et ambiguïté, apparentes, la science et la philosophie aristotélicienne mentionnées tout au long du *Trattati* fournissent une base pour les examiner comme démonstrations de concepts au-dessus de leur application immédiate pour l'architecture et l'ingénierie. En considérant ces appareils selon les termes de Di Giorgio, termes suggérés par ses propres expériences, ainsi que par ses écrits et ses peintures, de fortes associations peuvent être établies avec la science, la philosophie et la technologie de son époque.

Acknowledgements

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The Machines of Francesco Di Giorgio: Demonstrations of the World.

One day in the year 1475, Francesco Di Giorgio bowed before the Duke of Urbino and presented him with a finely tooled leather sheath of drawings. Frederigo ran his fingers along the edges of the smooth, thick paper, reading the opening page inscribed in his honour. Flipping each page over carefully, he examined the curious portfolio. The pages were full of drawings, no text, just hundreds of drawings of machines. The Duke recognized the familiar machines of war, and the winches and cranes not unlike those used in the construction of his palace, but there were also pumps, watermills, water wheels and countless other combinations of gears, cogs, and cylinders. He raised his head from the folio and smiled knowingly at the architect of his palace, his military comrade and fortification adviser. The capacity for invention represented in the numerous devices was impressive. However, the duke, a learned man, must have understood that more than just the skill of a talented engineer was demonstrated on the pages that lay across his knees. Frederigo nodded in approval at Francesco Di Giorgio, the man who had just given him his world.[1]

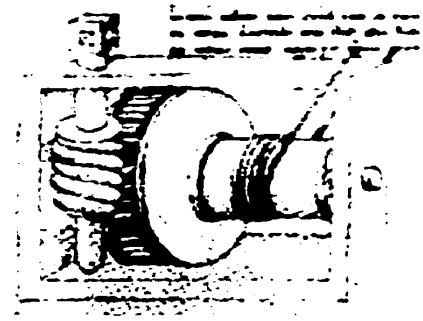

Figure 1 A winch from Francesco Di Giorgio's architectural treatise. f.91v TAV 318.

At that moment, the folio of drawings may have demonstrated to the Duke that Di Giorgio was worthy of his continued patronage, but they were also the early models for devices with which the architect would suggest so much more. His later architectural treatises would include entire sections of machines much like the ones in Frederigo's folio. These drawings would be accompanied by written descriptions that elaborated the function of each device and the size and relationships of all its pieces.

The inclusion of machines in an architectural treatise was not an unusual

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[1]This fictional account is based on the fact that Francesco Di Giorgio did do a folio of machine drawings in honour of the Duke. See Scaglia, Gustina. *Francesco Di Giorgio. Checklist and History of Manuscripts and Drawings in Autographs and Copies from ca. 1470 to 1687 and Renewed copies (1764-1839).* Toronto: Associated University Press, 1992.

practice. The model of all architectural treatises of the time was Vitruvius' *The Ten Books on Architecture.* In Book I, he outlines the three departments of architecture as: the art of building, the making of timepieces, and the construction of machinery.[2] He also suggests that each art is a process of interaction of theory and practice. The Vitruvian understanding of theory, unlike the removed, abstracted enterprise of contemporary architectural "theory", is a process of revealing, to the architect, himself, and to others, all the forces at work in making. It is not separate from architectural practice, but actually facilitates it by rendering the unforseen and the intangible aspects of a project visible. In the context of this Vitruvian model, Di Giorgio's machines have relevance beyond their possible implementation. The frozen wheels and cogs participate in a process of revelation, unveiling the properties and forces at work in their creation.

As Di Giorgio constructs them on the page, his devices reflect the concerns of everyday life in his time. The extensive depiction of water powered and water moving mechanisms reflects the concerns of Di Giorgio's community and of his own concerns as a hydraulic engineer. Grinding grain and olives, moving water from one place to another, lifting large objects and the other suggested functions for the machines were all necessary to sustain and facilitate life in fifteenth century Italy.

The philosophical and organizational structure of the later treatise based on Aristotelean natural science suggests another level of participation possible within Di Giorgio's devices. When seen in terms of causation, change, and principles of motion, the machine descriptions become scientific proofs. Within the numerous chambers and rooms of the machines lie a multitude of potential transformation of forces and possible interactions of the earth and the heavens.

Within the frames that contain these forces, Di Giorgio might be alluding to a theological dimension as well. Aristotelean cosmology was the basis for religious models of the world and heavens in his time. In his painting the

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[2]Vitruvius. *The Ten Books of Architecture.* Translated by Morris Hickey Morgan. New York: Dover, 1960. Book I, Chapter III, p.16.

Coronation of the Virgin, Francesco Di Giorgio translates the structure and logic of his devices into the organizing principles of the heavens. The actions of the machine, as they are revealed through the painting, achieve a significance that is no less than divine.

The space between the drawings and text of the machine chapters allows them to operate as architectural theory. As Di Giorgio emphasises repeatedly throughout his treatise, that which is not shown by the drawings, or described in the text must be provided by the knowledge and imagination of the of the architect. The chambers of water and wheels described on the pages of the machine chapters activate their reconstruction in the readers mind, harnessing the flow of things known - physics, cosmology, theology and things dreamt and imagined. In the imagination Di Giorgio's machines become *monsters* "in which the operational (functional) and the imaginative (symbolic) dimension of the invisible are made visible."[3] In their potential actions, the machines reveal not only the forces and concerns at work in the mind of Di Giorgio but they implicate the minds of other architects, other readers as well. They are in fact De-*monstrations* of the world.

In the process of understanding Di Giorgio's machines lies an opportunity for rethinking a practice of architecture today. When viewed instrumentally, Di Giorgio's mechanical depictions have their limitations. Most of the machines are housed in heavy frames, within which the movements of the mechanical elements would have been hindered. Also, the drawings - while communicating the general distribution and size of the parts - do not explicitly describe the connections between those parts. The scale of the illustrations is also not easily apprehended, except in those devices that include a horse or a man inside the device. The text, while giving sizes for the various wheels and major mechanical

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[3]Frascari and Sgarbi. On the Grotesque Body of Architecture: The Early Works of Aldo Andreani, Architetto Montavano. *Constancy and Change in Architecture*. College Station: Texas A&M University Press, 1991. P.111. Frascari elaborates this idea in *Monsters of Architecture*. Baltimore: Rowman and Littlefield, 1991. He explains *mostri sacri* as "extraordinary events, celestial novelties, untouchable sacred signs of a possible future."p.51.

elements, was not so explicit that these machines could have easily been realized. Nonetheless, as the following pages support, these machines do work as they are represented. But operating outside the conventional expectations of "working" drawings, Di Giorgio's drawings and text are reconciled with all the possibilities of their realization. Not just those aspects that can be represented in them but also those that must be brought to them. If these same spaces were to occur in "construction" drawings today, they might be provide an opening for reconciliation between the act of description (theory) and the act of construction (practice). Modern architectural practice might then become more sympathetic to its Vitruvian model.

An Architect of Siena

Francesco Muarizio Di Giorgio di Martino was born in Siena in 1439. Like the spirit of the noblewoman in Dante's purgatory who exclaims, "Siena made me . . .",[1] Francesco Di Giorgio would also be "made" from the influence of the city's geography, politics, culture and traditions.

Situated on the hills between the basins of the Arbia and the Elsa rivers, the city was a stop on the two most important trade roads in Italy; and, as a result, it courted a parade of foreign visitors. The importance of protecting these routes made fortification a necessity throughout the region and surrounding the city. Reinforcing the many existing fortifications against the new threat of cannon fire would be one of Francesco's primary tasks as a military engineer, and many of the defensive concerns of the region would find their way into the chapters on fortifications in his architectural treatises. In addition, the dignitaries and generals that would pass through Siena would introduce Francesco Di Giorgio to the spheres of influence in other regions of Italy. The importance of pleasing the visitors is reflected in Di Giorgio's discussion of the houses of the nobles and merchants in his architectural treatise, where he describes a series of rooms built for the sole purpose of entertaining and impressing foreign guests.[2]

Figure 2 The city of Siena. From an illuminated frontispiece. Original source and artist unknown. Reproduced from: *Francesco Di Giorgio e il Rinascimento a Siena 1450-1500.*

In the fourteenth century, with the shift of trade to the port cities and political upheaval and territorial disputes, Siena did not enjoy as much power and influence

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[1]Alighieri, Dante. *The Divine Comedy.* Translated by Laurence Binyon; annotated by C.H. Grandgent. New York: Penguin, 1977. *Purgatory.* Canto V. Line 134. p.213.

[2]Di Giorgio, Francesco. Trattato II, p.320.

as she had in the previous centuries, as a result, the region maintained a strong medieval character throughout the Renaissance. The city's profile was characterized by the towers of the many fortresses, belonging to the city's noble families. Siena's towers must have made a distinct impression on Di Giorgio's imagination, as they are represented frequently in his work. On a chapter on geometry and measurement he outlines several methods to survey their height from a distance, and in his machine chapters he describes devices to lift objects to their height.

Figure 3. A city from Di Giorgio's second treatise on architecture. *Trattato II*, f87v. TAV. 312.

The rich cultural landscape of Siena also contributed to Di Giorgio's development as an artist and an engineer. The strong artistic traditions of the previous century exemplified by Lorenzetti's *Allegory of Good and Bad Government* on the walls of the Palazzo Publico and Duccio's masterpiece *The Maestà* at the altar of the Duomo would have tremendous influence on the artists of Di Giorgio's time. The depth of the colours of Di Giorgio's paintings and the attention to the elaboration of the costumes and clothing would come from earlier Siennese traditions. The rich imagery of Dante's *Divine Comedy*, having been incorporated into the city's public rituals and storytelling, would have also contributed to the development of Di Giorgio's artistic consciousness.[3]

Figure 4. From Lorenzetti's *Allegory of Good and Bad Government*. Reproduced from *Francesco Di Giorgio e il Rinascimento a Siena 1450- 1500.*

The aspect of Siena that would be most

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[3] Hook, Judith. *Siena: A City and its History*. London: Hamish Hamilton, 1979. "Readings aloud from Dante formed a part of the cenacolo of St. Catherine..."p.124

influential to Di Giorgio's work is its water works. Siena's water was conducted in a complex system of underground aqueducts referred to as "Bottini". The prosperity enjoyed by Siena in the late middle ages resulted in a population surge, and the city's water grew more precious as demand for it increased. In the thirteenth century the Siennese regard for water and its system of fountains "bordered on the idolatrous."[4] Such reverence drew the waters of Siena into the city's rituals and legends. In the early fourteenth century the city supported organized efforts to find the Diana - a mythical river supposedly flowing beneath the city.[5] While the sacred character of water was probably not so direct by Francesco's time, its fountains did play a role in the city's festivals and parades. Work on the Siena's *bottini* beginning in 1469 was one of Francesco Di Giorgio's earliest commissions. Later he would become the city's engineer and would supervise the building of additional fountains, aqueducts, bridges and the draining of lakes for reclamation of the land.[6] These works, vital to Siena's sustenance and civic ritual, made Di Giorgio indispensable to his mother city. Therefore, it would be to Siena that other cities would have to appeal in order to contract the services of the much sought after architect and engineer. Siena, its traditions, its geography, both natural and man-made, and especially its waters, provided inspiration and justification for his architectural theories and his machines as well as his painted and built work. While his reputation as an artist, architect and engineer would take him all over Italy, he would always be "Maestro Francesco Di Giorgio of Siena."[7]

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[4] Hook, Judith. p.26

[5] Ibid, p.26. The mystical regard for water is also evident in early descriptions of machines where the water that powers them is often personified. See Gimpel, Jean. *The Medieval Machine*. New York: Holt, Rinehart and Winston, 1976. p.6- 7.

[6]Weller, Allen Stuart. *Francesco Di Giorgio Martini 1439 - 1501*. Chicago: The University of Chicago Press, 1943. p.31.

[7]Weller, Allen Stuart. In his biography of Di Giorgio Weller cited many official documents refering to the architect in this manner. pp. 1- 44. Vasari also describes him as "The Sienese sculptor and architect Francesco Di Giorgio..." *The Lives of The Artists Vol. II* London : H.G. Bohn, 1852. p.122.

In The Service of the Duke

Francesco di Giorgio served as architect and engineer to the Duke of Urbino, Frederigo da Montefeltro from around 1472 until the death of the Duke in 1483[8]. His time in the service to the Duke would prove crucial to the development of his architectural theories.

Figure 5. Frederigo di Montefeltro. Reproduced from *Francesco Di Giorgio e il Rinascimento a Siena 1450 - 1500.* p.355.

Frederigo, upon ascending to the office of Duke following the assassination of his brother in 1444, would instigate a series of monumental building projects to manifest the glory of the Montefeltro line. Francesco Di Giorgio was commissioned to assist in the rebuilding of the Cathedral, and he would also contribute to the design of several smaller churches in Urbino including the friary at the Church of San Donato, where the Duke's father's remains were kept.[9] In addition, while acting as architect for the Ducal palace, started by the architect Laurana, he supervised the carving of wall reliefs featuring implements of war and other machines very similar to the mills and hoists in his treatises.[10]

The Duke was a general of high regard, "the most successful condottiere in Italy," paid to defend the papal interests in the frequent territorial disputes that ravaged Italy in the Renaissance.[11] Acting as mentor as well as a patron, the Duke would have Di Giorgio accompany him on numerous military campaigns.[12] Di Giorgio's military experiences with Frederigo are reflected in the seventy fortresses

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[8]Ibid, p.119

[9]Clough, Cecil H. "Federigo Da Montefeltro: The Good Christian Prince." *Bulletin of The John Rylands University Library of Manchester 69* (1984-85), p.307. Note: Plan in Trattato 1, tav 21.

[10]Rotondi, Pasquale. The Ducal Palace of Urbino. It's Architecture and Decoration. p.69.

[11]Clough, Cecil.(1984-85).p. 310

[12]Dennistoun, James. *Memoirs of the Dukes of the Urbino: Illustrating the Arms, Arts and Literature of Italy, 1440 - 1630.* Vol. I. New York: John Lane Company, MCMIX p. 241. "Francesco Di Giorgio...ranks his generalship higher than any known to history from the days of old Rome, and acknowledges himself his debtor for many important suggestions as to fortification."

or defensive installations he executed while in his service, and in the lengthy sections on fortification and warfare in his treatises. [13] In addition, Di Giorgio may have paid homage to the Duke's military leadership in his first architectural treatise, beginning his section on military arts with a description of the ideal military captain:

> In prima della provvidenzia del capitano, el quale, debba savio, provvido e potente di suo, persona auldacie, bel parlatore, vigilante, dotto nelle scienzie, curiale, fedele, assueto nello guerre, crudele nelle battaglie, e sopra tutto secretissimo. E questo sono parti principali circa a la persona sua, e senza queste è come nave senza timone.[14]

A fine, richly decorated copy of his first treatise may have been executed for his patron.[15]

More important to Di Giorgio's development were the intellectual influences of the Urbino court. A very well educated gentleman, upon assuming the role of Duke, Frederigo began building a library of some significance. An account from the bookseller who supervised the acquisitions, Vespasiano, gives some sense of its scope:

> He has, in the first place, all the Latin poets, with their best commentaries: also the entire works of Cicero, with all the orators and grammarians in that language. In history, he commissioned every known work of the Latin and the Greek tongue, as well as the orators of the latter. In moral and natural philosophy, no author of these languages is wanting. In the faculty of theology he has been most profuse, having, besides the four doctors of the Church, St. Bernard, Tertullian, Hilary, Remigus, Hugh of St. Victor, Isidore, Anselm, Rabanus, Dionysius the Areopagite, St. Basil, Cyril, Gregory Nazarene, John of Damascus, Eusebius, Origen, St.

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[13]Connors, Joseph. Exhibition Review. "Francesco Di Giorgio Architetto. Palazzo Publico. Siena, 25 April - 31 July 1993." *Journal of the Society of Architectural Historians* 52 no.1 (Dec. 1993), p. 488.

[14]Trattato I, p.198.

[15]Scaglia, Gustina. *Francesco Di Giorgio. Checklist and History of Manuscripts and Drawings in Autographs and Copies from ca. 1470 to 1687 and Renewed copies (1764-1839).* Toronto: Associated University Press, 1992.p. 203.

> Thomas Aquinas, Albertus Magnus, Alexander de Alexandro, Duns Scotus, Bonaventura, Richard Mediavilla, Archishop Antonio, with all the modern doctors. There are further all the best civilians, with the lectures of Bartolomeo Capretti. He had the Bible, that the best of books, written in two volumes, with the richest and most beautiful illustrations, bound in brocade of gold, and lavishly ornamented with silver; and he made it be thus gorgeously adorned as the chief of all literature, and it has no equal in our time. There are also all the commentaries on the Bible in Greek and Latin, including Nicolo de Lira. He further has all the treatises on astrology, geometry, arithmetic, architecture, and military tactics, and a very curious volume with every ancient and modern military engine: also all books on painting, sculpture, and music; the standard writers on civil law; the *Speculum Innocentiaiœ*; in medicine, the works of Hippocrates, Galen, and Avicenna; the writings of Averröe on logic, ethics, and physics; a volume of early councils; the writings of Boethius on logic, philosophy, and music; and those of modern authors, with Pius II at their head. There are all the works of Petrarch, Dante, Boccaccio, Colluccio, Leonardo d'Arezzo, Fra Ambrogio, Gianozzo Manetti, Guarino, Panhormita, Francesco Filelfo, Perotto, Campano, Mafeo Vegeo, Nicolò Secondino, Pontano, Bartolomeo Fazii, Gasparino, Paolo Vergaio, Giovanni Argiropolo, Francesco Barbaro, Leonardo Giustiniani, Donato Acciaiuolo, Alamanno Remicini, Christofero da Prato the elder, Poggio, Giovanni Tartellio, Francesco d'Arezzo, and Lorenzo Valla. It was his object to obtain every book in all branches of learning, ancient and modern, original or translated. He had also of Greek classics, with their commentaries, Aristotle, Plato, Homer, Sophocles, Pindar, Menander, Plutarch, Ptolemy, Herodotus, Pausanias, Thucydides, Polybius, Demosthenes, Æschines, Plotinus, Theophrastus, Hippocrates, Galen, and Xenophon, the New Testament, St. Basil and other fathers in Greek with the book of Paradise, lives of Balaam and Jehosaphat; and all works on geometry, arithmetic, and astrology, as well as every other attainable writer in that language.[16]

Di Giorgio would have had access to this vast library, as well as exposure to the writings at meals, where the Duke required they be read. Following such readings, he would encourage discussions with his courtiers on such topics as theology,

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[16]Dennistoun, pp.165-167.

history, or philosophy.[17] Frederigo had "studied Aristotle's Ethics along with Maestro Lazzaro, a famous theologian."[18] He had also familiarized himself with the philosopher's other works and thus enjoyed the medieval commentaries of St. Thomas Aquinas and Duns Scotus which were the subject of many of the dinner table readings.[19] This may explain the strong Aristotelian character of Di Giorgio's architectural treatises. The oral readings and discussion may also explain how Di Giorgio could grasp the broad concepts of Aristotle, but in citing specific locations within the philosopher's oeuvre he was often mistaken. The other interests of the Duke also find their way into Di Giorgio's theories. "The kindred sciences of geometry and arithmetic were his (Frederigo's) favourite studies, and not long before his death, he had a course of these read to him by Maestro Paolo, a learned German astrologer, retained at his court."[20] Francesco may also have been influenced by the mathematical theories of Piero Della Francesca, "who was producing paintings to enhance the interior of the palace of Urbino at the time when Francesco Di Giorgio was bringing the building to completion."[21] Throughout his treatises Di Giorgio repeatedly emphasizes the importance of mathematics and geometry to the understanding and the making of drawings and

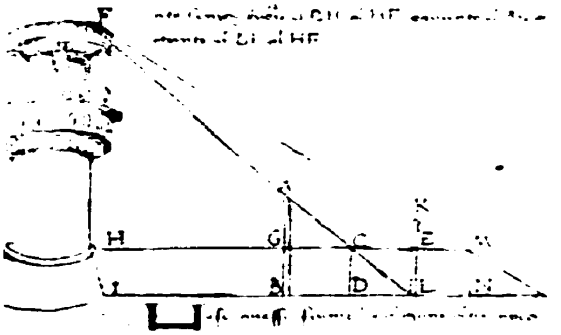

Figure 6. From a section on measuring the height of existing buildings in Francesco Di Giorgio's first treatise. *Trattato I.* f.29 TAV. 53.

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[17]Ibid, p.226.

[18]Ibid,p.230.

[19]Ibid, p.230.

[20]Ibid, p.231. Di Giorgio would have been in his service at this time, and a resident of the court. Di Giorgio served Frederigo from 1472 until the Duke's death in 1482 and continued in the service of his son Guidobaldo. See also Weller. p.8-13.

[21]Clough, Cecil H. "Federigo Da Montefeltro's Artistic Patronage" *The Journal of the Royal Society of Arts*,cxxvi (1978), p.718.

buildings,[22] But unlike Piero, who developed complex mathematical theories, Di Giorgio seldom discusses theoretical proportional systems. Instead, Di Giorgio uses specific ratios and proportional progressions to describe the relationships of elements to a whole. Francesco Di Giorgio's mathematics are grounded in his architecture, and it seems likely that he came to his knowledge of arithmetic and geometry, as he did his philosophy, through conversation, discussion and debate.

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[22]Trattato II, p.293-300. In the *Preambolo* to his second treatise, Di Giorgio gives one of his most involved discussions of arithmetic and geometry. But it is mainly anecdotal, not specific. His chapter on mathematics is concerned predominantly with measuring existing objects, buildings, distances.

The Writings and Drawings of Francesco Di Giorgio

Opusculum de Architecture.

The earliest set of machine drawings in finished form by Francesco Di Giorgio is a folio of drawings called the *Opusculum de Architectura.* Completed between 1470 and 1475, it was presented to Frederigo da Montefeltro, The Duke of Urbino, and the dedicatory inscription was written in his honour.[1] No text accompanies the voluminous series of engine drawings and fort plans and it has been concluded that they were intended as a demonstration of Di Giorgio's engineering knowledge to insure the continued patronage of the Duke. The folios included more than one hundred drawings of mills, pumps, gears for lifting and moving objects, diving apparatus, pile drivers, and even a sawmill, in addition to an almost equal number of illustrations of war machines and fort plans. From this assembly of engines Di Giorgio would extract the models for many of the machines included in his later treatises on architecture and engineering.

The Trattati

There are no existing original manuscripts for Francesco Di Giorgio's architectural treatises, but there were numerous copies made and circulated between fifteen hundred and eighteen hundred. This study primarily references the facsimiliar edition of Francesco Di Giorgio's *Trattati di Architettura, Ingegneria e Arte Militare, Vol. I and II* edited by C. Maltese and L. Maltese Degrassi published in 1967. The Maltese transcription of the earliest treatise, here in after cited as the *Trattato I,* was made through a cross referencing of two copies: the *Codex Ashburnaham 361*, from the Biblioteca Medicea-Laurenziana, Florence, and the *Codex 148 Saluzzo*, now in the Biblioteca Reale, Turin. Both copies were made between 1480 and 1503 at

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[1]Scaglia, Gustina. *Francesco Di Giorgio. Checklist and History of Manuscripts and Drawings in Autographs and Copies from ca. 1470 to 1687 and Renewed copies (1764-1839).* Toronto: Associated University Press, 1992.p.25. Scaglia has compiled a thorough listing of all the known copies, their histories, and current whereabouts.

the scriptorium at Monte Olivetto Maggiore, near Siena. According to Richard Batts, the original manuscript was probably completed in Siena about 1476.[2] Around 1504, during a visit to the library at Monte Olivetto, Leonardo Da Vinci annotated several sections of the text of the *Codex Ashburnaham 361*, particularly the chapter on geometry, which described concepts that Da Vinci would later include in the Codex Madrid II. This would lead to nineteenth century confusion regarding the authorship of the treatise. [3] The *Codex 148 Saluzzo* was probably intended for Frederigo Montefeltro, as it is ornately decorated with illuminated letters of gold beginning each chapter. [4] Editing notes and several additional drawings in Di Giorgio's own hand indicate that he supervised this particular edition.[5] Both treatises would not be attributed to Francesco di Giorgio until the mid nineteenth century, when Carlo Promis compared their illustrations with those of the later treatise that included Di Giorgio's name. The similarities between the subject matter and the particular illustrations of machines led him to attribute them to Di Giorgio, and not to Leonardo, as had been previously assumed. [6] Most of the twenty-eight known complete or fragmented copies catalogued by Scaglia were made in the sixteenth century, and originated from one of these two copies.

The later treatise, *Architettura Civile e Militare*, or the *Trattato II*, as it is most commonly referred to, was transcribed for the Maltese publication from the *Codex Magliabechiana II.I.141*, now in the Biblioteca Nazionale in Florence, and the *Codex S.IV. 4* from the Biblioteca Comunale in Siena. Dating this work has generated considerable debate. While the Maltese editors conclude a completion date of 1489,

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[2]Betts, Richard J. "On the Chronology of Francesco Di Giorgio's Treatises: New Evidence from an Unpublished Manuscript." *Journal of the Society of Architectural Historians* 36 no.1 (March 1977),p.14. Betts concludes that based on the limited understanding of Vitruvius the manuscript must have been written before Francesco Di Giorgio moved to Urbino in 1476. The influence of the humanist scholars in the Court of Urbino would lead to intellectual developments in his later works.

[3]Scaglia, Gustina. p.155.

[4]Ibid.p.203

[5]Ibid. p.189.MalteseXLVIII-L

[6]Scaglia, Gustina. p.22-23.

as it agrees with an astrological table included in the *Codex S .IV .4,* Gustina Scaglia, assuming it to have been completed after his work on a translation of Vitruvius begun in 1485, suggests an alternative date of 1490.[7] Betts agrees with the Maltese editors that *S.IV.4* was probably completed in 1489, but from the added references to Siena and the ruins around Naples in *Magliabechiana II.I .141*, he suggests that it was revised after Di Giorgio had returned to his home city from a visit to Naples in 1491. [8] Further, he cites a Neapolitan business transaction where, in 1492, Fra Giocondo and a painter were paid for a copy of 126 drawings from Francesco Di Giorgio - probably from the *Magliabechiana II.I .141* or something like it.[9] Displaying much the same calligraphy and spacing of the *Trattato I* copies made in the Monte Olivetto scriptorium, it is likely that the *Codex Magliabechiana II.I .141* was made there as well. Leonardo must have seen this edition in progress, as textual concordances between the treatise and Leonardo's work are here as well. Ladislao Reti lists the agreement by topic in the 1974 facsimilar edition of Da Vinci's *Madrid Codices.*[10] Leonardo could have seen the work at the same time as he studied the earlier treatise. He would have been familiar with Francesco Di Giorgio; they had met in Milan in 1490 while consulting in the cathedral and other structural problems at the request of Sforza.[11] The *Codex S .IV .4* was done in the Studio (Domus Sapientia) of Siena in 1490. Since the text had numerous words and phrases struck through in Di Giorgio's own hand, along with notations in the margins, it was probably considered a draft edition for a subsequent copy that was never

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[7]Ibid.p.251 On the translation of Vitruvius see p. 58-61. Trattato I,. p. LII on Astrological table.

[8]Betts. p.13.

[9] Ibid. p.12.

[10]Da Vinci, Leonardo. *The Madrid Codices.* National Library of Madrid. Facsimile edition of Codex Madrid II, MS 8937. Edited by L. Reti. New York: McGraw-Hill, 1974.p.94-96. Scaglia cites Heydenreich's more thorough concordance done in 1968. Scaglia, (1992)p.222.

[11]Weller, p.26.

made.[12] This later work, more clearly written and developed, had enduring influence for the next two centuries, with twenty seven copies being made- ten of them after 1700. The influence of Di Giorgio's treatise on the architectural writings of his immediate successors is made evident by the fact that Daniel Barbaro and Vincenzo Scamozzi, both had copies listed in their library inventories. And Barbaro, Scamozzi, and Palladio all refer to Francesco Di Giorgio's text when discussing the "camini," or vaulted warming rooms of the ancient house. The accompanying illustrations in Barbaro and Scamozzi's work are similar to those in the *Trattato II.*[13] Much later, another architect of note, Sir John Soane, would have a copy in his library as well.

The manuscript pages reproduced in the Maltese edition are from the Codex 148 Saluzzo, for the *Trattato I* and the *Magliabechiana II.I .141* for the *Trattato II.* In addition, a facsimilar of the Ashburnham Codice 361 transcribed and annotated by Pietro C. Marani was also consulted.[14] In the illustrations of machines the water is coloured. The wall thicknesses in the chapter on churches and the water circulating through the machines are the only elements illuminated. The coloured water clarifies the machine's operations, by actually showing water moving through the machines.

The Taccuino

The study and depiction of machines also occupy a large portion of Di Giorgio's *Taccuino* {*Codicetto: Codex Urb. lat. 1757*}, a pocket size sketchbook (8 x 6 x 3.5 cm) dedicated to machine and fortress designs.[15] Begun as early as 1460, it may

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[12]Scaglia, p 252. Trattato I, p. XLVII-L

[13]Ibid. p.261-263.

[14]Martini, Francesco Di Giorgio. *Il Codice Ashburnham 361, Biblioteca Medicea Laurenziana di Firenze. Trattato di Architettura di Francesco di Giorgio Martini.* Edited and transcribed by Pietro Marani. Firenze: Giunti Barbèra, 1979.

[15]Martini, Francesco Di Giorgio. *Taccuino:Urb. lat. 1757:seconda metà del xv sec.* Commentary by

(continued...)

have been used well into the 1490's, as its size would have been convenient for Di Giorgio's frequent travels outside Siena. It begins with machine drawings and descriptions translated from Mariano Taccola's engineering treatise *De ingeneis* .[16] The later drawings reflect Di Giorgio's own machine interests, and are shown in the tight boxes unique to his machine drawings. At the end is text from the book of Marcus Greacus, an early Byzantine work used predominantly by medieval chemists. [17] This text is copied from Taccola's *De ingeneis* Book II and was also included in Di Giorgio's *Trattato I.*[18]

Mariano Taccola

Many early machine drawings by Francesco Di Giorgio are based on engines in the notebooks of the Sienese engineer, Mariano Taccola. Taccola was known as "the Archimedes of Siena," and worked as an engineer in the city for the first half of the fifteenth century. Taccola was well respected, and held many significant public and political appointments over his lifetime. Initiating the instruction of technical subjects at the city's Studio he helped to establish Siena's reputation as a centre for technical expertise.[19] The studio, described as an "institution for learning by a non-

Figure 7. A mill from Taccola's *De ingeneis.* Prager and Scaglia. *Mariano Taccola and his Book De Ingeneis.* P.140.

(...continued)
Luigi Michelini Tocci. Milano: Jaca book, 1991.

[16]Prager, Frank D. and Gustina Scaglia. *Mariano Taccola and his Book De Ingeneis*. Cambridge, Mass.: MIT Press,1972.p.191.

[17]Ibid. p. 43.

[18]Ibid. p. 13.

[19]Scaglia, Gustina. "The Development of Francesco di Giorgio's Treatises in Siena." *Les Traites D'architecture de la Renaissance* Paris: Picard, 1988, p.91.

clerical student body of Europeans maintained by the community and staffed with teachers from Siena and abroad," was probably where Di Giorgio received his early education.[20] In this regard Taccola was an early - if indirect - influence on the young engineer, Di Giorgio. Mariano also wrote two manuscripts on engineering and machines. The first *De ingeneis* was completed in 1433, and his second treatise *De machinis* was finished in 1449. [21] Francesco probably had opportunity to copy drawings from Taccola's treatises and notebooks in the 1470's while working as a hydraulic engineer in Siena. Evidence of this "plagiarism" is found in the *Taccuino,* a sketchbook believed to have belonged to Di Giorgio at the time.

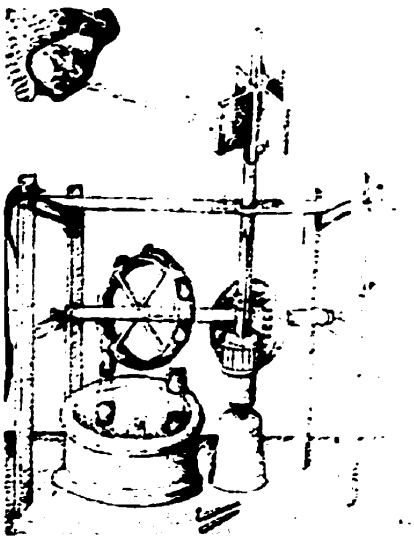

Figure 8. Taccola's windmill. Prager and Scaglia. *Mariano Taccola and his Book De Ingeneis.* P.140.

While Taccola's engines may have been the technical basis for Francesco Di Giorgio's machines, it is apparent from the ways the two engineers chose to represent their engines that Francesco's regard for the machine is fundamentally different from those of his predecessor. To begin most of Taccola's machines are drawn embedded in a particular site, his mills are drawn on the shore of a river or sea, his aqueducts drawn spanning the countryside from the originating spring to the cistern at the other end. Di Giorgio's devices are represented without contextual references in scaleless thick-walled boxes. While the gears and wheels of

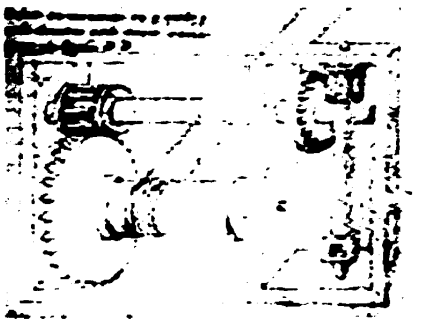

Figure 9. A mill from Di Giorgio's *Trattato II,* f.92 TAV. 319.

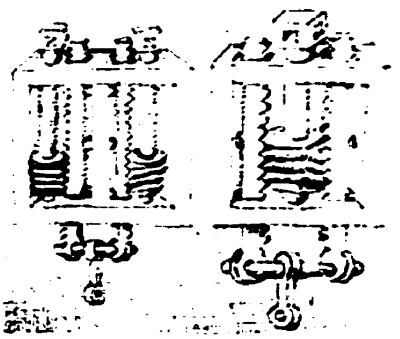

Figure 10. Hoists from Di Giorgio's *Trattato II,* f.93v TAV. 322.

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[20]Ibid, p.91.

[21]Prager, Frank D. and Gustina Scaglia. p.16-17.

Taccola's engines seem to float, held up by little more than the thin stiles on which they rotate, the elements in Di Giorgio's devices are held up by the substantial frames in which they are situated. Finally, in all of Di Giorgio's machine presentations, the *Opusculum*, his *Trattati*, and even the *Taccuino*, Di Giorgio depicts mechanical elements not used by Taccola including screws, toothed worm gears, and racks. While Taccola's interest may have been on the use or intention of the machine, Di Giorgio's emphasis appears more focussed on the pieces of the machines themselves: wheels, cogs, and gears all drawn in understandable relationships to one another. Through his particular drawing conventions and descriptive technique, Francesco Di Giorgio makes the machines his own, no matter where the mechanism may have originated.

The Machine Chapters

As discussed in the previous section, there were two distinct treatises authored by Francesco Di Giorgio. In the earlier treatise, *Trattato 1*, he divides his devices into two sections. One, captioned by the editors of the Maltese edition as *Leve Di Route e Mulini*,[1] concerns itself with the leverage of wheels in pulleys, particularly in regard to the workings of mills. The second section of machines, with the editors' heading of *Modi per Elevare e Condurre Acqua, Conche Navigabili, Argani, Gru e Verricelli* is concerned mainly with pumps, levers, and winches. In the *Trattato II* a more streamlined inventory of these same machines is organized into a single chapter; the *Settimo Trattato.* The descriptions of these machines, mills, pumps, winches, and carts reflect and illustrate the day to day concerns of civilian life in Di Giorgio's time. The predominance of water powered devices reflects the significance its mastery held for Di Giorgio as a hydraulic engineer and to the region he served. The organization of each chapter, the structure of the written commentary, and the accompanying illustrations all contribute to the mechanisms as they "work" on the page.

Trattato I

Francesco Di Giorgio begins the section *Leve Di Route e Mulini* with a discussion of the mechanical element that dominates most of the devices that follow: the wheel. He explains that, to arrive at how much a wheel can lift, one must divide the diameter of the wheel by half of the diameter of its axle. A geometric diagram is included in the margin of the page(figure 11), and a list of the progression of ratios of wheel to weight. He also discusses the relationship between the

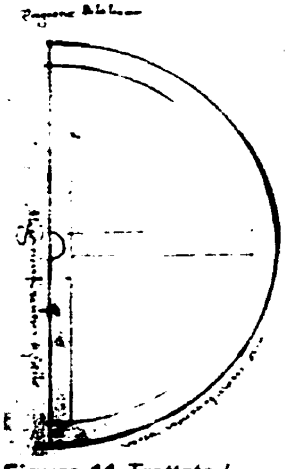

Figure 11 *Trattato I*, f33v TAV. 62.

[1] *Trattato I*, p.142. The 1967 edition of the *Trattato I* includes modern titles and headings to indicate the subject matter of the originally untitled folios.

circumference of the wheel and the weight it and its axle can carry. Di Giorgio begins his discussion of machines with a discussion of the proportional relationships between a single element and its mechanical function. By beginning his chapter with this discussion of the proportions of a specific part of machine, he conveys his concern for the proportions of parts to one another in the devices that follow. This becomes evident in the written descriptions of the individual machines: where the only actual sizes given are the diameters for each spool, gear and wheel in succession. And it is also demonstrated in the drawings: where a horse or a man might appear dwarfed by the gears and paddle wheels that surround it, but the gears themselves have an apparent "fit" with one another.

The relationship between the illustrations and text of the chapter is an additional concern for Di Giorgio, as he indicates in the discussion that precedes the machine descriptions:

> E per le simili ragioni le lieve delle rote son da fare, e massime in molti vari edifizi, come di mulini e altre cose che di continovo all' architetto occorrendo accade, siccome qui di sotto alcune formazion d'esse figurate mostraremo. Quantunque difficil sia in disegno ogni cosa demostrare, neanco per scrittura in alcun modo molte cose spriemar non si può, perché son tante le varietà delle cose interrotte e opposite l'una all'altra che a occupare si vengano, e però è necessario quasi di ciascuna cosa modello fare. Posto che molte cose all'animo dell'architetto paia facile, e che riuscir li debba, che mettendolo in effetto gran mancamenti in essi truova, in ne'quali con difficultà reparar vi può. Io per me delle invenzioni che qui demostrate seranno, d'assai buona parte , in me non confidando, spirienza ho veduta.[2]

In short, he states that it is difficult to describe things by drawing or even to explain them by written descriptions, but the mind of the architect can easily put the two things together. Di Giorgio includes this at the introduction of his section

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[2] *Trattato I*, p.142

of machines to make it clear that the drawings and text must be understood as a single entity for his descriptions to "work". The relationship between the machine illustrations and the accompanying text is further reinforced by the wording of the descriptions themselves. He begins many of his paragraphs with *this*, or *the present figure* [3] indicating that the drawing pre-existed its written description. He also concludes each description by once again referring to the illustration.[4] This sets up a circular relationship between the drawing and the text where the one always refers you to the other, not unlike the actions involved in some of Di Giorgio's own machines. Within this circular relationship, the reader's knowledge of the given elements and the subject matter at hand inhabits the center, activating its rotation and thus making the representation of the machine operate as Di Giorgio may have intended. Di Giorgio reiterates this concept of interaction between drawing and text on numerous occasions throughout both versions of his treatise. He felt as though it was important not only to understanding the significance of the machines, but to understanding other aspects of architecture as well. [5]

After his discussion of drawing and writing, Di Giorgio turns to individual machines. Most of these descriptions follow roughly the same structure. First he indicates the situation of the machine: in places where water is abundant, or in places where it is scarce, or still. Then he describes the sequence of wheels, toothed gears, and spools appropriate to the task. Within this sequence he may give the diameters of the various elements or simply their

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[3]Trattato I, p.143, p146, p.147 *questo*, *questa*, or *la present figura* respectively

[4]DiGiorgio ends typically with phrases like *...siccome la figura Q demostra, or ...che la figura S manifesta*, always referring to a particular illustration. In the Maltese edition the facsimiliar treatise does not show the letter designations on the drawings like the Ashburnham Codex. Martini, Francesco Di Giorgio. *Il Codice Ashburnham 361, Biblioteca Medicea Laurenziana di Firenze. Trattato di Architettura di Francesco di Giorgio Martini.* Edited and transcribed by Pietro Marani. Firenze: Giunti Barbèra, 1979.

[5]I elaborate on Di Giorgio's ideas regarding image and text in a later section *Disegno and Phantasia.*

relative sizes: great wheels, small teeth, tiny spool. Occasionally, he indicates specific materials: terra cotta pipes, jugs of clay, or a wheel of oak[6]. What is most consistent in the text is the sequence of movement as it passes through each of the elements. For example, here is a description of a water wheel :

> La figura del presente mulino non per furia ma per contrappeso d'aqua va. El cannone e tromba d'esso a uso di tramoggia, e l'aqua per piccola stremita uscendo, assai di forza agomenta. La ruota non manco di piei diciotto nel suo diamitro, er rocchetto del fuso d'essa pie due, er ribecco pie tre e mezzo, er rocchetto a denti della macina terzi due di pie, siccome la figura N demostra.[7]

First he distinguishes this machine as not moving by the force of water but by counterweight of falling water. Then he describes the sequence of the action. Water descending over a water wheel given a diameter of no less than 18 *piei*[8] turns a spool of two *pie* into a toothed wheel of three and a half *pie* which engages rollers on a spool on the axle of the grindstone of two thirds *pie*. Then he refers you to the specific illustration "N"(*figure 12*).

Figure 12. *Trattato I*, f35 TAV.65

The illustrations themselves seem to follow a particular model. Each machine is represented in a box. The scale and depth of the box conveyed by an unsystematic perspective. The section through the device is diminished to various vanishing points suggesting spaces adequate to house the device. Smaller chambers within the box

Figure 13. *Trattato I*, f40 TAV 75.

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[6]Trattato I, p.147, p.148, p.143 respectively.

[7]Ibid, p.146

[8]Ibid, p.146 *Piei* is the plural of *pie* - a unit of measure.

organize the numerous gears and wheels and their actions. Generally, the box is given no contextual reference. Where he might mention a river or stream in the written description, he will not indicate the water source in the drawing. Only the water within the machine is described. In the *Codice Ashburnham 361* version of the treatise the water is actually painted in blue, which helps in understanding the drawings.[9]. One of the only times he sets a device in a landscape is when he describes a siphon used to transport water over a mountain *(figure 13)*. Showing the river, the siphon and the mountain, he describes each as a working part of the device itself, much the same way the cogs and wheels are described in the mills. This method was taken directly from the sketchbook of Jacapo Taccola.*(figure 14)* And neither Taccola nor Di Giorgio must have attempted to realize this apparatus, as a siphon so large would never have worked.[10]

Figure 14. Taccola's Siphon. Prager and Scaglia, p.122

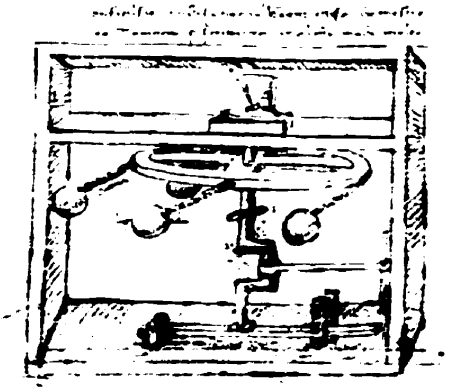

Figure 15 *Trattato I, f33 TAV.62.*

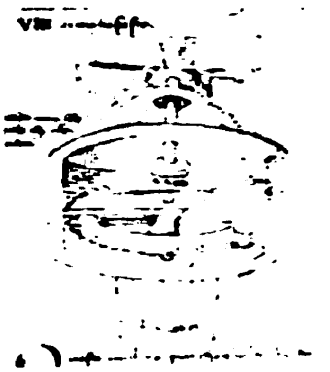

Figure 16. *Trattato I,* f37 TAV. 69.

While this siphon would not have worked, Di Giorgio should be credited with some innovations in the history of technology. One of the first mills he shows includes a ball and chain governor*(figure 15)*. Lynn White notes that this is one of the first

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[9]Martini, Francesco Di Giorgio. *Il Codice Ashburnham 361, Biblioteca Medicea Laurenziana di Firenze. Trattato di Architettura di Francesco di Giorgio Martini.*

[10]Prager and Scaglia. p.55. 34 feet is the absolute limit to the hieght of a working siphon due to the effects of atmospheric pressure.

documented instances of its use in Europe.[11] Within the chapter he also includes a description of a vertical axle windmill, based on one in Taccola's notebooks*(figure 16)*. Taccola's windmill is the earliest European evidence of that particular type of windmill.[12] Most of the windmills are depicted in cylindrical housings. Perhaps the housing is circular to emphasize the motion of the wind, which in Di Giorgio's time was believed to be circular.

Figure 17 *Trattato I*, f37 TAV. 69.

The watermills become more complex in the centre of the section, with multiple water wheels connected to various cranks and levers *(figure 17)*. These may have been attempts at perpetual motion machines. The force of water turning the water wheel moves the scoops that recirculate the water, which turns the water wheel *(figure 18)*. In depicting similar configurations in his notebooks, Taccola mentions the use of mercury to generate the motion.[13] Mercury was often used to animate models of these "perpetual motion" experiments. For example, *The Sketchbook of Villiard de Honnecourt* (1220-1240) also describes a mercury driven perpetual motion device *(figure 19)*.[14]

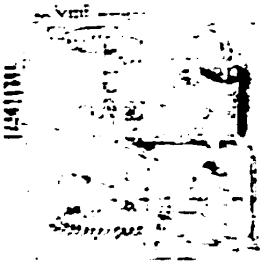

Figure 18 *Trattato I*, f37 TAV. 69.

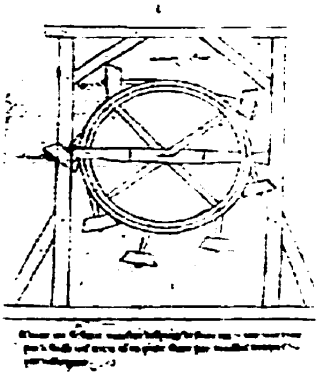

Figure 19. A perpetual motion machine. Villard de Honnecourt. p.122.

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[11]White, Lynn. "Tibet, India and Malaysia as Souces of Western Technology." from *Medieval Religion and Technology*. White suggests that it developed from Tibetian models, the knowledge of which could have been transferred by the many Far Eastern slaves in Italy at the time.p.49

[12]Ibid. p.48

[13]Prager and Scaglia.p.43.

[14]Honnecourt, Villard de. *The Sketchbook of Villard De Honnecourt*. Edited and translated by Theodore Bowie. New York: G. Wittenborn, 1959. p.14.The text reads: "A perpetual-motion

(segue...)

Di Giorgio does not mention mercury in his written commentary on his machines, but their complexity does imply more experimental concerns. The absence of mercury from the descriptions only reinforces the predominance of water in this section. Di Giorgio's experiences with the waters of Siena- both as an engineer who facilitates its use and a citizen who celebrates its power - are reflected in the numerous water driven devices described in this chapter.

Appropriately, this chapter predominantly featuring water-mills is followed by a section discussing the nature of water and how to find it. Given the heading *Sorgenti e Modi di Elevare e Condurre L'Aqua* by the editors, it begins with a discussion of the various theories on how water is generated.[15] Di Giorgio cites Aristotle's *Meteorlogica* as the origin of the theory of water created by subterranean condensation in caverns and caves. This theory would be particularly plausible to Francesco Di Giorgio, given the subterranean nature of Siena's water system. After an explanation of the origins of subterranean water, the rest of the chapter focuses on how to read the visible signs on the surface of the earth to find the invisible water beneath it. While a great deal of this is found in Vitruvius[16], the expectation that the unseen characteristics of nature are revealed by those that are observable is also an Aristotelian notion. And while Di Giorgio's later work includes numerous references to the philosopher, in this early treatise the citation in this chapter is the only instance in which Di Giorgio mentions the philosopher directly[17].

The section that follows is on metals.[18] Here, Di Giorgio elaborates the properties and availability of various metals, the first of which is mercury.

(...segue)
machine. Often have experts striven to make a wheel turn of its own accord. Here is a way to do it with an uneven number of mallets and with quicksilver."

[15]Trattato I, p.160.

[16]Vitruvious.Book VIII. p225-242.

[17]Trattato I, p.163.

[18]Trattato I, p.170.

Mercury has already been suggested as a possible agent in Francesco's perpetual motion experiments. In addition, knowledge of the mining and forging of other metals - iron and bronze in particular - would have been important for the fabrication of the various mechanical elements described in the previous and subsequent chapters on machines. This may suggest an organizational logic to the various sections. Understanding the nature of water and metals, both potential power sources for the machines, is crucial to comprehending their operation and construction.

Di Giorgio returns to machines in the next chapter. *Modi per Elevare e Condurre Acqua, Conche Navigabili, Argani, Gru e Verricelli*, includes various water pumping mechanisms, followed by methods for lifting and transporting wieghts; and concludes with self propelled carts.[19] Di Giorgio begins this chapter in familiar territory. Water again. Having instructed the reader on how to find water in the previous chapter, he shows how it must be brought to places that need it. The engineer's solution is to bring the water over the mountains to the city through a series of pipes and aqueducts. By corking and uncorking the connections between the water source and the various pipes and cisterns, the flow of water can be mediated.[20] There follows a description of a series of locks that can make narrow, shallow water navigable by large ships and of the detailed workings of a small fountain. Without naming Siena, the water works of his home region are evidently the ones depicted in these first descriptions.
After discussing these larger, more civic works, Di Giorgio shifts his scale to a smaller, more complex, mechanism: the water pump. Almost thirty methods for pumping and lifting water are catalogued in the pages that follow. In the conclusion to one of his pump descriptions, he suggests why the devices are necessary:

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[19]Trattato I, p178.

[20]Ibid, p.178

E questa acqua per canali in ne'luoghi dove bisognasse è da condurre. E anco far mulini, e alcun altro esercizio che di bisogno fusse, siccome la figura v manifesta.[21]

The water can be carried to places that need it, or used to power mills and other machinery. Water pumps are significant because they bring power to Di Giorgio's other water devices.

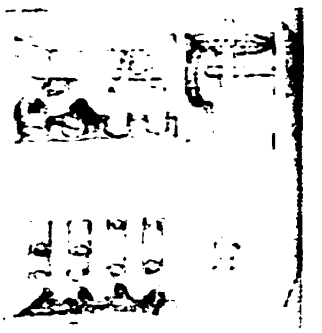

Figure 20. An example of a pump. *Trattato I*, f45v TAV. 82.

Most of the pumps consist of a pair of valved chambers with interlocking cylinders that are operated in combination with various levers, cranks and wheels. As in the written descriptions of his mills, Di Giorgio follows the path of water through the various mechanical elements. Here the description moves backwards from the valve where the water will first enter the device to the handcrank. It isn't until the conclusion of the paragraph that the water to be pumped is actually mentioned. It is as if, after describing the device, he verbally activates it by restating its function: lifting water. Then he directs you to the accompanying drawing.

The pump illustrations themselves are notable for their use of an unusual drawing convention. The pumping chambers are drawn as if they were transparent. In this way the internal workings can be shown without sacrificing the complex external configurations. Di Giorgio is one of the earliest to use this device and his use of it illustrates his concerns regarding the limitations of drawings in communicating an entire concept.[22] As Di Giorgio will explain in Book Four of his second treatise:

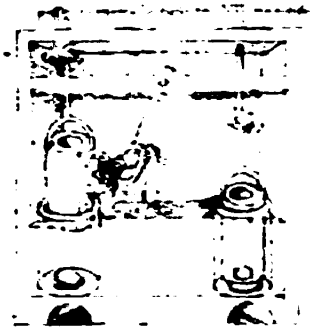

Figure 21. *Trattato I*, f46 TAV. 83.

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[21]Trattato I, p.181.

[22]Ibid, p.136.

> Oltre a questo, quelli disegni che sono messi per esempli in ogni parte, non possono essere in tutto dichiarati, perché le superfice estrinseche coprono le intrinseche, onde non volendo multiplicare in infiniti esempli è necessario che, overamente le parti esteriori sieno imperfette facendo perfette le interiori, overo per contrario et econversamente.[23]

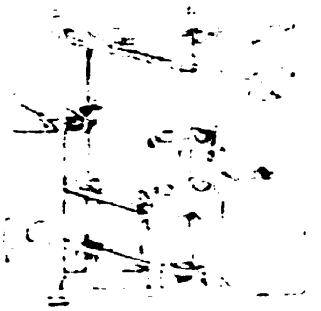

Figure 22. *Trattato I,* f46 TAV. 83.

Di Giorgio addresses this problem of representation with his own ingenuity; using his cut-away sections to describe both the inside and outside of his subject at the same time.

The water pumps indicate mechanical innovation as well. There are diagonal as well as vertical pumping shafts, several involving the use of large screws to circulate the water up through the device. On several of these diagonal configurations - as well as on many of the vertical cylinder pumps - the engineer uses an elliptical loop at the connection between the cylinder and the crank shaft *(figures 23 and 24)*. This innovation, credited to Di Giorgio by historian Lynn White, enhances the pumping action by preventing the inner cylinder from binding on the walls of the pipe shaft.[24] Another innovation was the use of parallel cranks attached to a single power source used on several of his more complex

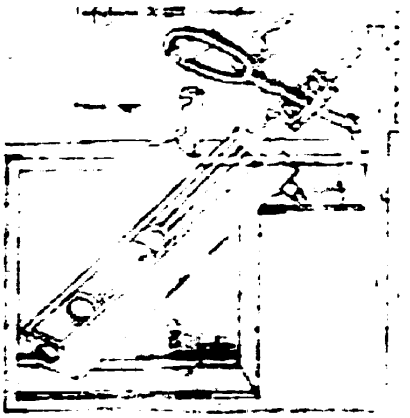

Figure 23. *Trattato I,* f47 TAV.85.

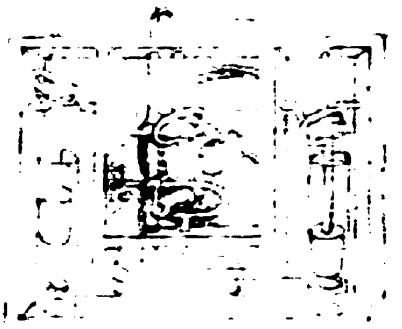

Figure 24. *Trattato I,* f47 TAV.85.

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[23]Trattato II, p.484. Translated in Edgerton Jr., Samuel Y. *The Heritage of Giotto's Geometry : Art and Science on the Eve of The Scientific Revolution.* p.138. "Moreover, those drawings that are set forth as examples everywhere cannot be completely explained, because the outside surfaces obscure the interior. Not to multiply infinite examples, either the exterior parts truly have to remain imperfect while the interior parts are made perfect or vice versa. Therefore pictures and writing have to be supplemented with ingenuity. "

[24]Edgerton Jr., Samuel Y. *The Heritage of Giotto's Geometry : Art and Science on the Eve of The Scientific Revolution.* Ithaca, Cornell University Press, 1993. p.139.

pumps. This was a significant improvement on earlier crank and connecting rod set-ups *(figure 24)*. [25]

From pumps, Di Giorgio returns to water wheels like the ones used to power the mills detailed in the preceding chapter. But here he isolates the various water lifting methods. First a hand cranked bucket and chain wheel. Second a wheel of scoops powered by another horse wheel *(figure 25)*. Finally a chain of discs pulling water up though a cylindrical pipe. All of these were depicted in the earlier chapter in combination with other mechanical elements to facilitate the workings of the mills.

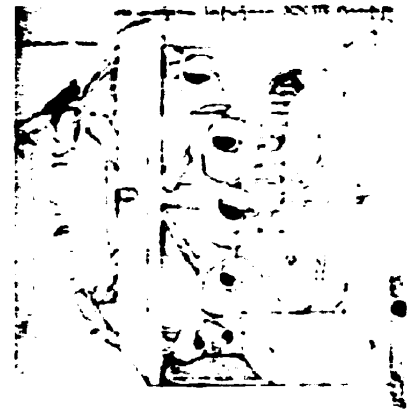

Figure 25. *Trattato I*, f48 TAV. 48.

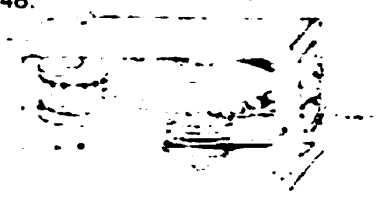

Figure 26. *Trattato I*, f49v TAV.90.

The devices that follow address the problem of lifting great weight. Most of them are variations of a winch or capstan, but horizontal hoists are also described. Di Giorgio begins each of his written descriptions by directing the building of a frame. Although most of the machines described in the treatise are drawn contained in such frames, this is one of the only times he specifically mentions it within his written description. This may be because he must allow for the ropes to escape their container *(figure 26)*.[26]

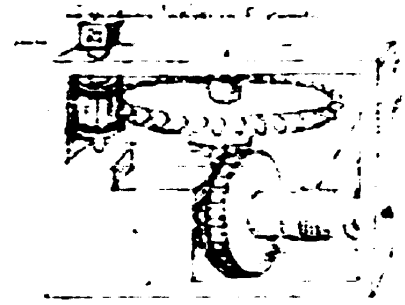

Figure 27. *Trattato I*, f53 TAV.97.

As with the earlier descriptions of mills, where there was little or no mention of what was being ground, the text regarding the winches ends at the rope as it passes out of the frame *(figure 27)*. What is actually being lifted is not a concern. This is reflected in the illustrations; the ropes simply end as soon as they pass

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[25]White, Lynn. *Medieval Technology and Social Change*. p.114

[26]Trattato I,p.190. "I quali a due rotelli che nel telaio sono passando, a la carrucole over calcesi si riferisca, siccome la figura I manifesta."

through the walls of the box. When describing a horizontal conveyance, Di Giorgio does include references to that which is carried both in the text and in the drawing. While using the generic term "*edifizio*" in the written description, in the drawings he illustrates various building elements being transported: columns, cubes, obelisks and pyramids *(figure 28).*

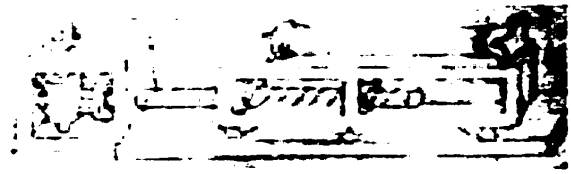

Figure 28. *Trattati I,* f50 TAV. 91.

The section concludes with mechanical carts. They are powered manually, as Di Giorgio puts it " pulled without beasts, it can be done with *"ingegno".*[27] The carts employ the same mechanical elements of the other devices- toothed wheels, screws, levers, rollers, etc... But here they are combined in much more complex configurations *(figure 28).* By multiplying the interactions involved, Di Giorgio increases the number of cranks needed to power the cart. Since they were generally used in celebrations, parades, and processions, the option to involve more participants may have been deliberate. The chapter concludes curiously with an amphibious craft - simply a boat set in a wheeled frame - to be used on land or at sea *(figure 30).*

Figure 29. *Trattato I,* f52 TAV. 95.

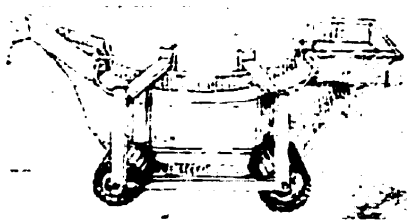

Figure 30. *Trattato I,* f.53 TAV.97

There are other machines in the *Trattato I.* In the chapter on the military arts, war machines of antiquity and of Di Giorgio's time are discussed. These machines are best discussed within the context of Francesco Di Giorgio's contributions to military engineering, so I will not elaborate on them here, except to note that Di Giorgio must have held them in a different regard, as the standard box containers he uses for his civilian machines are

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[27]Trattato I. p.195 "Quando alcuna carro per tirare senza bestie, ma con ingegno fare si può,..."

largely absent from the illustrations involving the war machines. Di Giorgio does include a few more devices in a brief chapter described by the editors as *Congegni e Consigli Practici Diversi* or "Mechanisms and Diverse Practical Recommendations".[28] The section includes systems of pulleys for wells *(figure 32)*, ways of raising water, ways of moving over and under the water, drills *(figure 31)*, augers and instruction as to climbing a battlement or crossing a course of water.[29] The wells and drills of this chapter are held to the same drawing convention as Di Giorgio's other machines - contained in tight boxes, drawn in an oddly foreshortened one-point perspective.

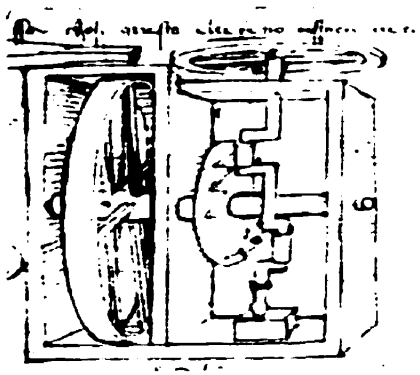

Figure 31. *Trattato I*, f67 TAV.125

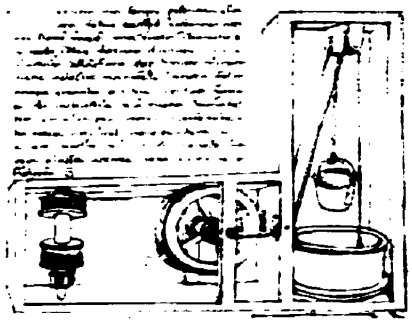

Figure 32. *Trattato I*, f66 TAV.163

[28]Ibid, p.240-243.

[29]Trattato I, p.240.

Trattato II

Di Giorgio's second treatise *Architettura Civile E Militare* is more systematically organized. Divided into seven books, it was probably developed in the spirit of Vitruvius' Ten Books, as Di Giorgio had been working on a translation before he began this treatise[30]. As in Vitruvius' *Ten Books of Architecture*, the final book is the chapter devoted to machines. Di Giorgio's logic for leaving the machines until the end is evident in the first lines:

> Peroché nello edificare è necessario di trasportare pesi di luogo a luogo li quali senza ingegno per forza con grande incomodo possono essere maneggiati, e similmente nelli edifici si ricerca trarre acqua assai, et alla perfezione della casa, rocche e castella fa di bisogno di pistrini e mulini, perché non in ogni loco si ha comodità di acque per macinare, e dove è comodità non è nota la ragione della simmetrie della rote e parti del mulino, in questo mio ultimo trattatello metterò alcune macchine più necessarie sì da trarre pesi in alto et ad ogni differenzia, sì da attignere e trarre l'aqua per le ditte comodità e per le case.[31]

As he states, the machines are necessary for the perfection of the buildings discussed in the previous chapters. These are the specific tools that facilitate the architect in his work.

But the machines also have value in themselves. As he notes, "Where it is appropriate it is noted the reason in the symmetry of the wheels and the parts of the mill."[32] Throughout both his treatises it is *ragione,* or reason, that makes the work of man meaningful, therefore it is essential to architecture. Di Giorgio's machine descriptions - both text and drawings - make the reason and symmetry of the mechanism apparent.

Having stated his intentions, Di Giorgio spends a great deal of time

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[30]Scaglia, Gustina, p. 58-61.

[31]Trattato II, p.492.

[32]Ibid. p.492. "...e dove è comodità non è nota la ragione della simmetrie della rote e parti del mulino..."

discussing the sacrifice and effort that went into accumulating the knowledge to build such machines and his fears that the rewards for such sacrifice might be taken by those of lesser stature who copy his devices and take credit for them. He retells the story of Diogenes that Vitruvius includes at the end of his chapter on machines.[33] This anecdote is also concerned with the credit due a man possessing such mechanical ingenuity. There are several issues at work here. The first is that Di Giorgio uses the model of the Vitruvian chapter to set up the framework for his own and feels it appropriate to discuss the same considerations. Then there is the fear of imitation. Di Giorgio's own words on the subject:

> Ma questo ancora saria piccolo affano se non seguisse uno maggiore incomodo all'animo e molestia, peroché sempre e massimamente oggidi li ignoranti, facendosi onorati delle fatighe aliene, e si gloriano con parole di sapere e potere molte cose, le quali se la verità si cercasse si trouvaria invenzioni d'altri; e questo vizio nelli tempi mostri abbonda in quelli che architetti si chiamano precipuamente, li quali sono quasi tutti omini ignoranti et inesperti, che per le opere loro facilmente si può comprendere.[34]

This bears striking resemblance to a similar tirade that Brunellesci apparently shared with Taccola, who recorded it in his notebook - the same notebook that Di Giorgio copied machines and descriptions from early in his engineering career. In the conversation Brunellesci says:

> Do not share your inventions with many persons; share them only with men who understand and love science. If you disclose too much about your inventions and achievements, you give away the fruit of your genius...God's gifts to us must not be divulged to envious and ignorant people who ridicule them. We must act as men of wisdom, strength and ingenuity. We must not show the crowd our secrets about waters flowing in ocean and river, or the devices that work on these waters. Let a council convene, with an assembly of experts

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[33]Trattato II, p.493. Vitruvius. Book X, p.315.

[34]Trattato II, p.492-493.

> and masters in mechanical art, to discuss plans and construction of the work. Everyone- the educated ones and the morons- wishes to hear the proposal. Intelligent men understand it; they understand at least something, partly or fully. Morons and inexperienced men understand nothing, not even when things are explained to them. Ignorance promptly moves them to anger; they remain ignorant, although they want to show themselves intelligent, which they are not. These men persuade morons to think as they, feebleminded, do and to scorn intelligent men. Blockheads and morons can do much harm in questions about aqueducts, the means for forcing water, their subterranean and terrestrial ascending and descending, and about buildings in or over salt of fresh water. We love those men who know about these things. We ought to keep away from those who know nothing. The headstrong charlatan should be sent to war. A council should be formed only of wise men, who bring honour and glory to the republic. Amen.[35]

Di Giorgio continues to elaborate on his fears of losing stature to others less worthy. He includes another story from Vitruvius, where the man who challenges Homer's stature, when Homer - long dead - cannot defend himself, is eventually disgraced.[36] This may allude to an incident that involved Di Giorgio personally. As mentioned before, the engineer's expertise was requested from many cities and communes who were engaged in building fortresses and developing defence strategies. In 1483 while in the service of the young Guidobaldo, Duke Frederigo's son, Di Giorgio became aware of rumours suggesting that he had aided enemies of Siena in the construction of fortifications. In his letter to the Lords of the city of Siena he wishes a similar disgrace for his accuser. Di Giorgio states that by his actions "this person makes himself known to your Lordships as an evil individual. And this could not be more to my advantage, nor should I know how to demand of God a more just

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[35]Prager and Scaglia, p.11-12.

[36]Trattato II,p.494. Vituvius. BookVII, p.197.

vengeance. "[37] While Di Giorgio suffered no dishonour from the incident -he was made city engineer two years later - he may have still felt its sting when he wrote his treatise.

Figure 32 *Trattato II*, f.91 TAV.317.

After this discussion Di Giorgio continues by retelling the story of the philosopher Aristippus, also from Vitruvius.[38] As the tale goes, Aristippus is shipwrecked on the shore at Rhodes, and upon seeing geometrical figures drawn in the sand he exclaims, "Let us be of good cheer, because I see traces of men."[39] Di Giorgio elaborates on the importance of teaching philosophy and geometry to the young, in order to make such human traces possible. Di Giorgio concludes his introduction with the statement *"Imperoché tutti i presenti della fortuna dati, da quella facilmente si tolgano, ma le virtuose disipline non mancano mai ma rimangano stabili insino all'ultimo della vita."*[40] Di Giorgio may be referring to the "good works" evidenced by the treatise and the "good work" the machines that follow make possible.

Then Di Giorgio turns to machines. First, a few ways that with reason great weight can be moved more easily: winches.[41] In general, he indicates that they all need to have cog wheels, spools, and gears with teeth. And, indeed, the five winches that are described all use various combinations of those elements. As

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[37]Weller, p.14. Weller includes his own rough translation of the letter as well as a transcription of the original. Document XL.

[38]Vituvius. Book VI, p.167.

[39]Ibid. p.167.

[40]Trattato II. p.495. Because all the gifts given by fortune can easily be taken away, but the virtuous works, they do not fail but remain steadfast until the end of life.

[41]Trattato II. p.495. Pigliando pricipio dalli argani è da dichiare alcuni modi per li quali con ragione maggior peso e più facilemente si porrà movare.

for what turns the spool, in all but one of the devices demonstrated, it is a simple crank inserted into a die. The other, indicated in the text as being turned by one man, is depicted in the illustration being turned by a horse inside a large wheel. The sixth and final of the winches is a crane construction similar to one in the earlier treatise. The winch raises the height of the support, and the object is raised and moved by screws. In comparison to the earlier descriptive text, the description here is more detailed. He includes what each piece is made of, and he is much more explicit in how it interacts with the other pieces.

Figure 33. *Trattato II*, f.91v TAV.318

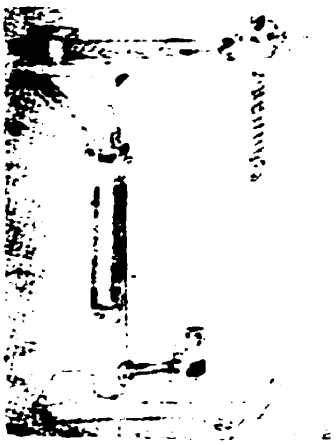

Figure 34. *Trattato II*, f92v TAV.320.

Then Di Giorgio states that there are many weights that cannot be pulled by ropes; so it is necessary to use screws of metal to pull columns, pyramids and other objects of the greatest weight.[42] The section that follows is indicated in the margin notes as *Viti*, or "screws."[43] The four machines described all use screws - mostly bronze - to engage a worm gear or roller to lift the desired object. The first uses a screw and worm gear to pull a pyramid horizontally into place. The other three methods are for vertical lifting. Considering the number of examples Di Giorgio included in his earlier treatise, it is apparent that

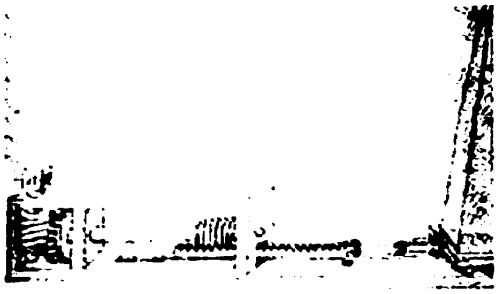

Figure 35 *Trattato II*, f.93 TAV. 321.

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[42]Ibid, p.498. E perché molti pesi sono che per forza di canapi non si possono tirare perché non è canape che resistesse, però bisogna trovare alcuni ingegni che per vie di metallo si possino tirare, come sono colonne, piramide, e altri edifizi di grandissimo pondo...

[43]Ibid, p.498.

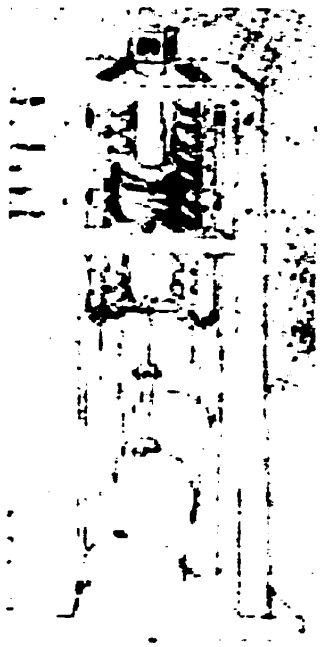

Figure 36. *Trattato II*, f.94 TAV.323

he is not presenting these as developments of one another but as carefully selected solutions to particular conditions or problems.

The next section is indicated in the margin as *Trarre d'acque* or "Drawing water". Two water pumps are described. Both are again rendered as if transparent, so that the valves and connections inside can be seen. The first uses a cylinder of wood or other material with a shaft of iron through its centre. At the base of the shaft is a plate the same size as the cylinder with two valves. At the bottom of the cylinder are two valves as well. The plate is lowered into the cylinder by a counterweight attached to the shaft. When it is raised, the valves close and water is lifted to a spout at the top where it pours into a container. The other method uses a bellows to pump the water up through a pipe into a container.

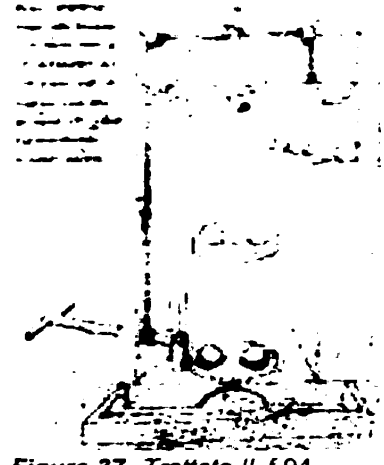

Figure 37. *Trattato II*, f.94 TAV.323

Mulini, or "water mills", are next. Here he offers only two methods. In the earlier treatise, he filled almost an entire chapter with them. Both examples are quite simple. One uses a large top fed water wheel to activate three other toothed wheels that finally turn the millstone. The second mill uses a horizontal water wheel to simply rotate the shaft that turns the millstone. Concluding the section on *mulini* is an illustration of a horizontal axle windmill that has no accompanying text.

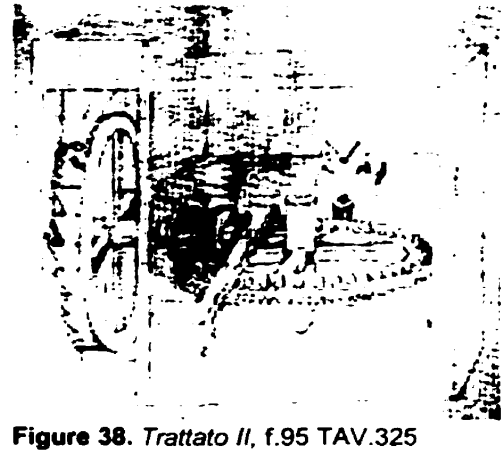

Figure 38. *Trattato II*, f.95 TAV.325

Pistrini, or "mills not powered by water" are the last machines discussed in the chapter.

Seven examples are given, beginning with two hand cranked machines that use a ball and chain governor to regulate their motion. These are followed by three mills - all involving various combinations of a trio of wheels, with rotation transferred through intersections of rollers or teeth. All have a tooth and die at the bottom, in anticipation of a beast to set the works in motion. The rotation of all the elements ends up at the chamber at the top of the box that houses the millstone. Smaller that the rest pf the box below, with a simple pitched roof, the inclusion of the millstones seem like an afterthought.

Figure 39 *Trattato II*, f.95v TAV.326

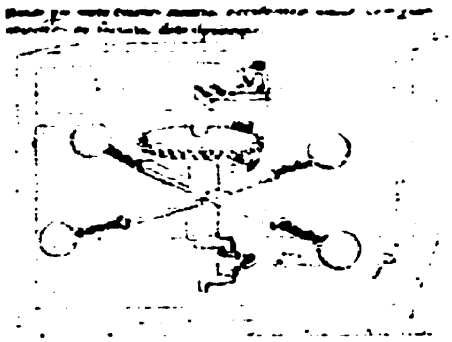

Figure 40 *Tr II*, f.96 TAV.327

The chapter finishes with two mills powered by the hooves of a horse. The first situates the horse at a feeding trough in a chamber above the great wheel it turns. This rotation activates a combination of three wheels, not unlike those of the previous mills. And finally, Di Giorgio indicates a large wheel which the horse is intended to run inside. The animal sets a more complex sequence in motion - engaging five wheels that ultimately turn the millstone.

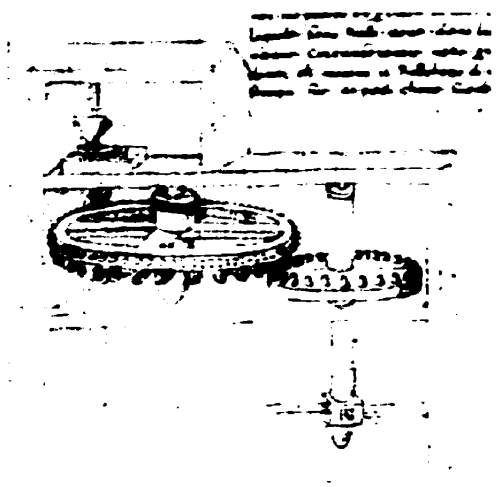

Figure 41 *Tr II*, f.96v TAV. 328

The chapter on machines is followed by a brief, philosophical conclusion, reiterating earlier discussions of the infinite capacity of the mind of man, scattered throughout the treatise. Di Giorgio argues that this allows for man's potential for the endless variation on the things that he makes, as opposed to other animals that make or build from instinct. He then speaks again of the importance of architects understanding drawing, as this is the principal

way to communicate these infinite variations to others. And all of this makes it possible for the architect to "work rationally with the essential aid of God from which all virtues are produced."[44]

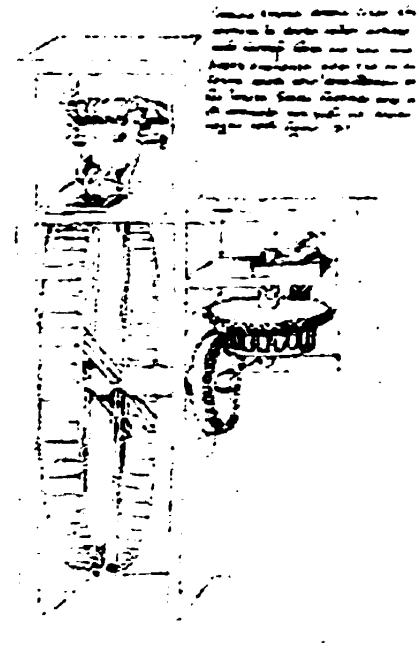

Figure 41 *Tratt. II*, f.97v TAV.330

[44]Trattato II, p.506 "...e ragionevolmente operare con l'aiuto del fattore dell tutto da cui tutte le virtù sono concesse."

> ...saria molto utile e quasi necessario che l'architetto, overo chi vole pigliare frutto alcuno da questa mia picola opera, intendesse qualche poco di disegno, peroché senza quello non si può bene intendere le composizioni delle parti dell'architettura,...[1]

The machine chapters have been understood to be merely a demonstration of Francesco Di Giorgio's technological knowledge and experience. While they do represent Di Giorgio's skills as an engineer, when considered in the context of Di Giorgio's architectural theory they suggest Di Giorgio's regard for them as part of the overall work of the architect. By the mediation of forces - visible and invisible- in the multiple wheels and cogs, Di Giorgio's devices are invested with the potential to reveal a significant, symbolic order accessible to man only through his own works.

Throughout both treatises, and repeatedly in the sections on machines, Di Giorgio emphasizes the relationship between the drawings and the text. It is Di Giorgio's own understanding of the space between his illustrations and their written descriptions that provides an opening to explore further what these devices might have meant, and how they were intended to work.

Figure 43. From *Francesco Di Giorgio e il Rinascimento a Siena 1450-1500.*

To begin, Di Giorgio's attitudes toward illustration were shaped by early experience. Di Giorgio, while a student at the Studio in Siena, had worked on illuminations. He did the illuminations for the first page of a manuscript of Albertus

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[1]Trattato II, p.483 -484. "It would be very useful and almost necessary for the architect or anyone who wants to seize any fruit of my little work, to understand a bit about the art of drawing since without that one can't understand the composition of the parts of architecture,..." Translation from Edgerton Jr., Samuel Y. *The Heritage of Giotto's Geometry : Art and Science on the Eve of The Scientific Revolution.* Ithaca, Cornell University Press, 1993. p.138.

Magnus' *De Animalibus* in 1463.[2] The page depicted an "allegory of Chastity", a maiden with a unicorn in the left column, and in the margin three scenes from the Labours of Hercules. Three years later he did an illumination for *Super Primo sententiarum; Alphonsi summi theologi Ord. S. Augustini,*(1463).[3] Traditionally, the illustrations of a manuscript were meant to provide images that could aid in the recall of the text. They did not so much graphically represent the text as augment it.

The drawings in Francesco Di Giorgio's treatises were intended to illuminate the text in much the same way and he elaborated on this in many discussions of *disegno* throughout his treatises. For Di Giorgio the knowledge of *disegno*-"a term that he uses to designate both the process of composition and the expression of ideas in terms of drawings" is crucial to the conception and execution of architecture.[4]

Drawing is crucial because, based on principles of mathematics and geometry, it lends legitimacy and certainty to the art of architecture.[5] By emphasizing the scientific nature of architecture, Di Giorgio supports his attempts within his treatises to treat architecture scientifically. Drawing - being apprehended by sight, the most noble of the senses - is more directly absorbed by the intellect.

> "Queste determinazioni sieno suffizienti quanto alla cella tonda et sé simili col supplemento del disegno, nel quale il senso del vedere q giudicherà più che l'audito, come più e nobile senso e di più differenzie iudice, come afferma Aristotile nel proemio della Metaphysica, e massime in questa arte la quale potissimamente considera cose visibili come invisibili."[6]

Revelation depends on *disegno*. It allows for consideration of things visible and

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[2]Weller, Allen Stuart. *Francesco Di Giorgio Martini 1439 - 1501.* Chicago: The University of Chicago Press, 1943.p. 65.

[3]Ibid, p.65.

[4]Lowic, Lawrence. "Francesco Di Giorgio on the Design of Churches: The Use and Significance of Mathematics in the Trattato." *Architectura; Zeitschriftfr Geschichte der Baukunst* 12 no.2 (1982), p.160.

[5]Francesco Di Giorgio. *Trattati di Architettura Ingegneria e Arte Militare*, p. 293.

[6]Ibid. p.399.

invisible.

Nevertheless, drawings have their limitations. There are so many possibilities for the reader to put the words with his own images. Likewise, without illustrations the text can be interpreted in ways "much different from the truth."[7] But, when writing is put together with *disegno,* the sign is connected to it's meaning and things hidden can be known.[8] For Di Giorgio, the potential for the intellect to comprehend the author's intention is dependent on the combination of text and drawings.

The combination of illustrations and written descriptions produces a complete idea of the subject - assembled in the imagination of the reader. The images produced by the interactions of text and *disegno,* were referred to by Di Giorgio as *fantasie.* This term, used by Di Giorgio in discussions and references to *disegno,* was linked to the way the memory process was understood to work.

The Italian *fantasie* comes from the Greek *phantasia.* Plato used it to discuss the visions of madmen and prophets.[9] Such visions, having little or no relation to the world as experienced, were created - without reference - in the mind of the beholder. Aristotle's understanding was tied more directly to the mechanism of memory. In his commentary on Aristotle's books of *Senses and Sensation of Memory and Reminiscence*, Thomas Aquinas elaborates on the process of remembering. One of the central actions involves *phantasia.* Aquinas defines "*phantasia*" as "similarities of concrete things"[10]or as" an image that leads us to something else; and, therfore, it is the principle of remembering."[11] He locates memory in the soul and suggests two ways for the act of remembering to engage the phantasm. The

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[7]Ibid. p.489.

[8]Ibid. p.489. "Ma quando tali autori concordassero con la scrittura el disegno, molto più apertamente si porrebbe iudicare vedendo il segno col significato, e cosi ogni oscurità sarebbe tolta via. "

[9]Kemp, Martin. Kemp. Martin J. "From "Mimesis" to "Fantasia": The Quattrocento Vocabulary of Creation, Inspiration and Genius in the Visual Arts." *Viator* 8 (1977), p.367.

[10]Aquinas. Aquinas, Saint Thomas. *Commentary on Of Memory and Reminiscing from Aristotle's books on Sense and Sensation.* Translation by ?. Unpublished. p.3.

[11]Ibid. p.7.

first is to understand the phantasm as itself - an image - and to consider its properties as such. The second way is for the memory to apprehend the phantasm as an image of something else, generating thoughts of the thing to which the *phantasia* refers. The first process is static, simply understanding the thing as presented. The second is creative. A new image is created from the combination of the *phantasia* and other remembered experiences. In Di Giorgio's time, the Platonic and Aristotlean origins of the term mingled into a concept of "creative" assembly.[12] *Fantasie* are conceived in the individual imagination - not unlike the visions of Plato's madmen - but informed by past experience and accumulated knowledge. A passage from Francesco Di Giorgio's *Trattato I*, from the section on forts and other types of defence, demonstrates that Di Giorgio understood the term similarly:

> E perchè volendo descrivare tutto quello che en tale facultà s'appartiene sarebbe quasi impossible, e faccenda infinita a raccontare molte diverse e strane **fantasie** le quali sicondo luogi e siti adattar bisogna, ed anco perché assai son quelle che la lingua o penna spriemer (esprimere) no le può, le quali lo intelletto cogitando vede, ma solo è da pigliare el suggetto delle cose le quali l'architetto con ragione componendo aggionare e diminuire può. [13]

The diverse *fantasie* that Di Giorgio presents cannot describe the infinite variations that are possible. They cannot all be spoken or written either. Therefore, the mind of the architect must adapt the drawings and descriptions to respond to the problems of his particular situation. The *fantasie* given in the treatise represents

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[12]Martin Kemp in his article *From "mimesis" to "Fantasia"*, also sees *fantasie* as a part of a more inventive, imaginative process that develops into the creative will of the individual artist. Emphasizing its Platonic origins, he uses Filarete's extensive use of the term to substantiate his position. He does mention Di Giorgio's use of it in reference to garden design, but he does not acknowledge any other occasions, nor he does not explore his usage of the term any further. Instead focusing on Di Giorgio's usage of *ingegno.* p.361-373.

[13]Trattato I, p.19.And because it is almost impossible to describe all the things that in such ability appear, and infinite matters to relate many diverse and strange fantasie which in accordance to sites and places it is necessary to adapt, and also because there are those which the tounge or pen cannot express, which the intellect understands, but the architect alone takes the suggestion of those things and with his reason he is able to add to or take away pieces.

Di Giorgio's own imaginative/adaptive process and acts as the basis for the same in other architects.

In the conclusion to the *Trattato II* Di Giorgio explains that the *fantasia* would not be possible without *disegno*:

> Et ultimatamente, come nel principio è ditto, dato che alcuno nella **fantasia** avesse ordianto alcuno ragionevole edifizio o vero instrumento, volendo quello fare componare e fabbricare, non puo senza il **disegno** esprimare e dichiare el concetto suo;...[14]

For Di Giorgio the *fantasie* is the result of the interaction of drawings and text in the imagination of the architect. And the drawings and text demonstrate that same process in his own imagination.

> Sieno adunque a suffizienza li esempli descritti alli ingegnosi lettori perché facile cosa è a la invenzioni agiognare, applicando i remedii sicondo i difetti, restando le superfluità e non mancando nelle necessarie cose. [15]

Di Giorgio relies on the connection between the text and drawings to reveal his intentions. By doing so he creates the opportunity through which, using knowledge of his life and experiences and careful study of his treatises and other work, we might inform our own *fantasie* of his machines and how they work.

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[14]Trattato II, p.506

[15]ibid. p.505.

Aristotelian Causation and Significant Actions in the Trattato II

> For the point of investigation is to acquire knowledge, and a prerequisite for knowing anything is understanding *why* it is as it is-in other words grasping its primary cause.[1]

Francesco Di Giorgio's *Trattato II* contains numerous references to Aristotle and his teachings. *The Metaphysics*, *The Physics*, *De Anima*, *Meterorlogica*, *Ethics*, *Posterior Analytics*, *Politics*, and *On Generation and Corruption* are all cited. Knowledge of these works may have come from discussions and readings at the Duke of Montefeltro's dinner table. More significant than the frequent references to the philosopher, Di Giorgio uses the principles of Aristotle's natural philosophy to structure his entire treatise, from the organization of the chapters to the individual descriptions of each mechanical device. Framed in Aristotelean terms, the significance of Di Giorgio's machines can be drawn beyond their practical applications to broader concepts regarding the nature of the world.

For Aristotle, there are four types of causes. There is the substantial or material cause, "that from which a thing is made."[2] Then the formal or essential cause is the shape or structure of a thing, and the efficient cause is "the original source of change or rest."[3] The final cause is its end, or that reason for which a thing comes to be. These are foundations for Aristotle's arguments in both his Physics and Metaphysics, and they are also the organizing principles for Francesco Di Giorgio's second treatise *Architettura Civile E Militare*.[4] In his *preambolo* he states as much, suggesting that his work should follow the scientific model of working from the

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[1]Aristotle. *Physics*. Translated by Robin Waterfield; with an introduction and notes by David Bostock. New York: Oxford University Press, 1996. p.38.

[2]Ibid. p.39

[3]Ibid. p.39.

[4]Lowic, Lawrence. "Francesco di Giorgio on the Design of Churches: The Use and Significance of Mathmatics in the Trattato." *Architectura; Zeitschriftfr Geschichte der Baukunst* 12 no.2 (1982), pp.153-1534. Lowic discusses the aristotelian structure of the treatise before dealing specifically with Di Giorgio's principles of church design.

general to the specific.

> In lo prima si determinarà di alcune proprietà generali a ciascuno delli altri 6 particulari, seguendo la sentenzia di Aristotele nella sua Fisica, dove insegna che dalle cose universali in le singulari nelle scienzie bisogna procedere.[5]

The *Primo Trattato* enumerates the general rules and principles necessary to the art of architecture. It also discusses the elements and materials from which architecture is made - or its substantial causes. The second through sixth books divide architecture into distinct building types - houses and castle, cities, temples, forts, and ports respectively. In this general outline, these types would be architecture's formal causes. The *Settimo Trattato*, the chapter on machines, describes the specific implements that make it possible to build and sustain all the other aspects of architecture: the efficient causes. Di Giorgio's philosophical conclusion is concerned with the final cause of architecture; that is, the glory of God and Man.

Di Giorgio repeats this structure within each chapter. Beginning each with a discussion of the final cause, or the ends to which a specific species of architecture is directed, he then elaborates the particular means to execute that cause. Naming the attributes necessary to the architect to execute a particular edifice, he describes architecture's efficient cause, or the skills of the architect. He describes the substantial causes, the appropriate materials, for a particular type of structure.[6] Laying out the generating geometry, dictating how the rooms should be distributed and what shape they should be he illustrates the formal causes of a building.

The final cause of the machines is to aid in the building process and further to perfect those things already built, as Di Giorgio states in the first sentence of the Settimo *trattato*:

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[5] *Trattato II.* p.299.

[6] Lowic states materials are primarily dealt with in the first book of the treatise(p.153. But materials as they relate to specific buildings,which is what designates them as causes, are discussed in the individual chapters.

> Peroché nello edificare è necessario di trasportare pesi di luogo a luogo li quali senza ingegno per forza con grande incomodo possono essere maneggiati, e similmente nelli edifici si ricerca trarre acqua assai, et alla perfezione della casa, rocche e castella fa di bisogno di pistrini e mulini, perché non in ogni loco si ha comodità di acque per macinare, e dove è comodità non è nota la ragione della simmetrie della rote e parti del mulino, in questo mio ultimo trattatello metterò alcune macchine più necessarie sì da trarre pesi in alto et ad ogni differenzia, sì da attignere e trarre l'aqua per le ditte comodità e per le case.[7]

The machines for lifting things participate in the construction process, while mills and water pumps bring sustenance to the buildings. Grouped by these final causes, the winches and other lifting devices come first, followed by water pumps, and, finally. mills. In the earlier treatise, much less thoughtfully organized, seeing such a clear organization in the sections on machines is difficult.

As he describes each individual machine he lays out the other three causes. For example, in this passage, where Di Giorgio describes the third method for making a winch:

> ...si facci uno stile alto tre e mezzo. grosso uno piè, in nel mezzo del quale sia una vite di bronzo, coi pani piani in diametro piedi uno e due terzi, el quale percuoti in una rota rullata con rulli di bronzo in diametro piedi tre e mezzo, la curba dello stile della rota sia in diametro piedi uno e mezzo, come appare nel segno...[8]

The material cause in this case is bronze, for the screw and the rollers. The formal cause is in the disposition of the stile, the screw, the wheel and the spool of rope in relation to one another to make the winch. And the efficient cause here and for all the machines listed is not just the skill of the architect who conceived them , but the man or animal that moves them, implied here in the drawing by the die at the top of the box, ready for a

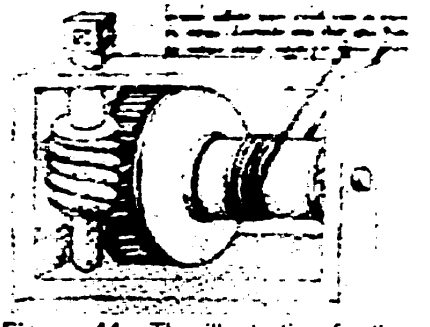

Figure 44. The illustration for the description. *Trattato II*, f91v TAV. 318.

[7]Trattato II, p.492.

[8]Trattato II, p.496.

crank to be inserted to activate the machine, propelling it to its final cause of lifting great weight.

Di Giorgio uses causation as a framework in which to organize his architectural theory. By considering the relative causes of architecture's constituent concerns, houses, temples, forts, and machines he reinforces its consideration as a science.

Aristotelian natural philosophy considers observation of change and its causes to be the foundation of scientific discovery. Change lies innate in almost every substance. *"The actuality of that which is potential, when that which is potential is active not as itself but as something which is capable of change."*[9] There are three varieties of changes that can occur in the terrestrial world. The first two involve opposing conditions. There is substantial change, which describes the states of corruption and generation. Then there is change that involves increase and decrease, both quantitatively and qualitatively. [10] And finally, there is change of place where a body is transformed by being moved.[11]

Movement , according to Aristotle, must be the primary change, as it must have occurred for the other two to take place

> ...still before anything comes into being something else must be in motion--something which is not coming into being, but which already exists--and this in turn must be preceded by something else.[12]

Due to its position of primacy, Aristotle spends a great deal of time considering movement and its properties. "In its broadest signification, it concerns the structure of the sublunar world; and in the narrowest and most restrictive sense, it involves

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[9]Aristotle. *Physics.* Book III.p.58.

[10]Grant, Edward. *The Foundations of Modern Science in the Middle Ages. Thier Religious, Institutional, and Intellectual Contexts.* New York: Cambridge University Press, 1996. In the chapter "What the Middle Ages Inherited from Aristotle."p.56.

[11]Aristotle. *Pysics.* Book IIII.p57.

[12]Aristotle. Physics.p.214.

the specific place of a single body."[13] Through the course of *The Physics* and continuing in *The Metaphysics*, and *De Caelo*, Aristotle proceeds to transform the basic principles of motion and change - concepts like"everything that moves is moved by another" and "change takes place in the object changed, not in the agent of change" - into assumptions about celestial motion and the nature of the first mover.

Francesco Di Giorgio's machines either grind things into smaller pieces by moving water or air, or they lift and carry things to different places. While the mills alone involve qualitative and quantitative change, all of the machines in Di Giorgio's treatises involve change of place. Not only as their end, as when they actually move something; but also in their means to that end, as all their parts move each other. They are coincidental agents of the change that occurs in the object or substance they act upon, while being objects of change at the same time.[14] The text and the drawings of the machines act as demonstrations of those changes, revealing each mechanical element's potential for action by its proximity to other agents capable of being moved as well.

Aristotle's theories of motion are intricately involved in his ordering of the universe, separating the unchangeable world of the stars from the changeable and mortal world of the earth. The movement and change in the substances of the terrestrial world has its basis in the properties of the four elements. Water and earth, being heavy are inclined to fall or move downward towards the earth's center. Fire and Air are light, and move naturally upwards - rising away from the earth. Everything in the Aristotelian world is made of combinations of these four, and their potential motions are determined by the ratio of the heavy elements to the light. Stemming from the natural inclination of the elements to move up or down, the natural motion of all things on earth is reciprocating, linear motion.

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[13]Grant. p.57.

[14]Physics.p.195.

The heavenly realm is made of ether, and ether's natural disposition is to move in rotation. This was to explain the movement of the stars throughout the night, and their orbit throughout the year. Because circular motion is not reciprocating-- "because something which is moving from A will simultaneously be moving to A on the same forward path (for it is moving towards any point that it will reach), without undergoing opposite or contrary movements"-- circular motion is considered continuous.[15] Celestial rotation, considered infinite, must have been caused by an infinite, immobile agent, the first mover, the *primum mobile*.

Most of the technological developments Di Giorgio made in his engine designs have to do with some sort of mediation, or translation between linear and circular motion. The screws he uses in his lifting and moving devices translate the circular rotation of the screw into the linear movement of an object, vertically or horizontally. His winches do this as well, achieving vertical motion of an object as the result of the circular winding of a spool. In his pumps, Di Giorgio initiates the addition of an elliptical loop in the connecting rod, within which the crank arm, encased in a rolling sleeve, slips back and forth as it turns.[16] In investigating problems of continuous rotary motion in his mills, he found that the ball and chain flywheel efficiently smoothed the mill's rotation, allowing it to approach the uniformity of Aristotle's eternal circular motion.[17] As the result of his thorough consideration of both linear and circular movement, Di Giorgio can exploit the potential energy in both, simultaneously.

Beyond technical innovation, Francesco Di Giorgio is also concerned with the larger implications of the interaction between the two motions. To him the represent the resolution of the immortal world of the heavens and man's mortal existence on earth. This is probably the reason he cites Aristotle's *Metaphysics* frequently, since

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[15]Aristotle. Physics. p.223.

[16]Edgerton, Samuel.p.139.

[17]Aristotle.Physics. VIII.8. p226.

its proper subject is substances: sensible substances, both corruptible and incorruptible, and immobile , insensible substances (that of the first mover). [18] He begins each book of his Trattati addressing man's metaphysical predicament: possessing an incorruptible, immortal intellect while trapped in a corruptible mortal body. In the beginning of the *Trattato II*, in the book on houses and castles, the architect, in the face of such circumstances is moved to ask if building is really necessary.

> Questo avviene a li omini circa all'arte dell'architettura: però che molti sono stati, secondo la legge naturale vivendo, li quali si sono persuasi ch'el sia supervacaneo e pestifero el fabricare al mondo suntuosi edifici; e delle ragioni loro queste sono le potissime.[19]

Building may distract man from his happiness and his advancement towards a good end.[20] But as houses are necessary for man to live, he concludes:

> Adunque concludendo possiamo dire che senza alcuno [vizio] si puo edificare secondo che la natura inclina ciascuno farsi uno domicilio secondo la intenzione sua, se da li antecessori non lo ha posseduto, e quello fare con amena apparenzia et esistenzia secondo la ragione della architettura, pero che el medesmo dispendio regulato rende l'edifizio congruo, comodo [e] durabile, che senza norma di architettura produce in tutto contrari effetti.[21]

Architecture is good if it follows the model of nature and, executed with reason, is found commodious and durable. Durability is contrary to man's mortality and corruptibility. For although a building may one day deteriorate, much as the ruins Di Giorgio illustrated from his travels through Italy, it will take them much longer in comparison with man's fragile existence. Architecture helps man participate in relative incorruptibility.

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[18]Conway, O.P. *Metaphysics of Aquinas. A Summary of Aquinas's Exposition of Aristotle's Metaphysics.* New York: University Press of America, 1996. p.274. While this is from the *Metaphysics* XI, I find this version clearer in this instance.

[19]Francesco Di Giorgio. *Trattati II.* p.324

[20]Francesco Di Giorgio. *Trattati II.* p.327.

[21]Francesco Di Giorgio. *Trattati II.* p.327

While buildings are in themselves corruptible, their existence and variation is to Di Giorgio a demonstration of man's infinite capacity for invention.

> Questo medismo le opere sue dimostrano, però che tutti li altri animali operano, come similmente ogni irondine nidifica e similmente ogni ape overo aranea domifica, ma nell'intelletto umano essendo l'arte con la forza assegnata, tutte le opare sue, le quali sono quasi infinite, infinito varia.[22]

Man's inventions are mortal, material manifestations of his immortal mind.

Francesco believes that man's situation, suspended between the mortal and eternal, can be reconciled by Architecture. And in the fourth book, on temples, he cites Aristotle's *De Anima* as the source of the following argument for such a possibility:

> ...peroché li omini debbano con ogni industria e sollicitudine accostarsi alle cose divine quanto a lui è possible, però che in questo consiste sua felicità, sì come ogni cosa aprossimata alla più perfetta da quella riceve perfezione, e così è conversamente. Delle quali cose ne segue che li mortali debbano, e con la mente, e cone voce et orazione, e con li atti morali et ultimo con le opere manuali, laudare e glorificare el fattore del tutto, a denotare che da lui solo ogni sua virtù e bene recognosca.[23]

The mortal can, by approximating perfection, receive perfection. His mind, his voice, his moral acts and his manual work, praise and glorify the maker of all. Therefore human work - architecture - can approximate heaven through acts of mimesis. This is why Di Giorgio's ideal temple is round. It is based upon the model of the celestial realm. It allows man to gesture towards the incorruptible heavens and the insensible, immobile mover that moves them eternally.

Francesco Di Giorgio's machines can also be understood as mediators between the two realms. They are a mimetic portrait of the Aristotelian world describing the combination of terrestrial - linear - and celestial - circular - motions. As such, they

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[22]Ibid. p.506.

[23]Ibid. p.371.

are also indicative of man's condition, mediating between eternity and mortality. The text and drawings of the machine chapters are descriptions of these significant actions. They produce *"fantasmic"* motions in the mind, that suggest potential for actual movement in the world.

Considering the metaphysical dimension of the actions taking place among the mechanical elements, the mute boxes that house them take on added significance. By isolating the device from its site and its product, it allows for the device to be understood in terms beyond its instrumentation. This may explain Di Giorgio's consistent illustratration of the machines in boxes, despite the fact that, as historians of technology have pointed out, the thick containers would have severely impeded their efficiency.[24] In fact, Di Giorgio may not have intended them to be read as boxes, or containers, but as frames - frames for significant action.

Figure 44. *The Virgin and Child Enthroned with Angels and Saints.* From *Siena, Florence, and Padua: Art, Society and Religion 1280-1400.* p.83.

This technique of framing depicted in the illustrations of the machines has its origins in the traditions of early perspectival painting, where specific events of a given narrative were "framed" pictorially, in order to present all aspects of the story simultaneously. In such paintings, often large wall paintings, significant moments are isolated from one another, usually by a box of sorts, sheathed in architectural elements. A specific example is in the altarpiece for the Duomo of Siena by Duccio(1311) with which Di Giorgio would have been familiar. The *Maestà*, an elaborate two sided structure, depicts on its front face *The Virgin and Christ Child*

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[24]Scaglia, Gustina. *Francesco Di Giorgio. Checklist and History of Manuscripts and Drawings in Autographs and Copies from ca. 1470 to 1687 and Renewed copies (1764-1839).* Toronto: Associated University Press, 1992. *p.19. "Slow movement would indeed result from Francesco's combinations of gears screws, racks, and wheels for pumps, mills, hoists, and new forms of vehicles such as cars(...for ceremonial processions) These new components are always confined in the limited space of a box frame which would render them inoperable since the animal yoked to the handlebar completed the revolution over a wide path."*

Figure 45. *Scenes from the Passion of Christ.* From *Siena, Florence and Padua: Art, Society, and Religion 1280-1400.* p.84.

Enthroned with Angels and Saints (figure 44). But of more interest to the discussion is the opposite side, which reveals *Scenes from the Passion of Christ* --twenty six discrete moments describing the events leading up to Christ's Resurrection *(figure 45).* These moments are isolated in separate "rooms" or buildings, with the perspective conventions being isolated to each piece, as opposed to extending through the whole array. While perspective is suggested, it is not actually constructed. The "space" of the painting is merely suggested in order to site the particular activity within the realm of natural experience. Each view represents a suspended moment, its action implied by the recognizability of the figures involved and their relationships to one another and to the frame in which they are located. Repetition of characters, or "sites", enhances the narrative thread of the entire piece. One of the most prominent paintings in all of Siena - indeed "the richest and most complex altarpiece to have been created in all of Italy"[25]- the altarpiece would have been an inescapable component of Di Giorgio's artistic consciousness.

Like the individual panels in *Scenes from the Passion of Christ*, Di Giorgio's

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[25]Norman, Diana. "'A Noble Panel': Duccio's *Maestà.*" *in Siena, Florence and Padua: Art, Society, and Religion 1280 -1400.* Volume II. Edited by Diana Norman. New Haven: Yale University Press, 1995. p.80. Quoted from White, J. *Duccio: Tuscan Art and the Medieval Workshop*, London, 1979, p.80.

machines represent action in suspension. The space within his boxes allows the theoretical description of natural and violent motion to take place. And the repeated elements - toothed wheels, screws, rollers, cranks - suggest a mechanical logic that becomes almost a narrative sequence through the course of the chapter, not unlike that of cycle paintings like the *Maestà.*

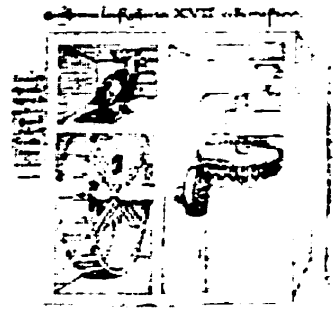

Figure 46. *Trattato II.* f38 TAV. 71.

The boxes, by emphasizing the motions and changes within, are also considerations of Aristotle's principle that change is in the object changed and not in the agent of change. The transformations that Di Giorgio is interested in are those that occur within the walls of the box. The object that is moved, the grain that is ground are not his primary concerns; therefore, he does not show them. By separating the machines from the objects they act upon, he assures that the changes or motions that occur among its parts are considered in their own right.

The Prayer Machine

As stated before, Aristotle attributes the only eternal motion of the universe to circular motion. The circular motion of the heavens is that motion that causes all the others. And it is made continuous by its proximity to first mover. This first mover, an agent of change that has no magnitude, is located at the outer edge of the universe.[1] The arguments of *Physics VIII* and *Metaphysics XII* , which focused on the nature of the first mover, were the subject of much theological interest in the middle ages, as they were read by many as scientific proofs of God's existence. If circular motion is a product of the will of God - as Thomas Aquinas suggests in his commentary on the *Metaphysics*[2] - then what can be inferred from machines that demonstrate such motions? Francesco Di Giorgio considered the circular form most appropriate for churches, because the circle was associated with the heavenly realm and would be most pleasing to God.[3] Did Di Giorgio intend for consideration of the potential movements of his machines to act as a meditation on Divine Will?

Francesco Di Giorgio had precedent for his understanding of the machine as a mimesis of the divine. A similar vision is demonstrated by Vitruvius at the beginning of his tenth book, which discusses various useful machines where he states:

> *All machinery is derived from nature, and is founded on the teaching and instruction of the revolution of the firmament. Let us but consider the connected revolutions of the sun, the moon, and the five planets, without the revolution of which, due to mechanism, we should not have had the alternation of day and*

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[1]Aristotle. Physics VIII.10,p.227.

[2]Conway, O.P. *Metaphysics of Aquinas. A Summary of Aquinas's Exposition of Aristotle's Metaphysics.* New York: University Press of America, 1996. p.284.

[3]*Trattato I*, p.233-234. *Trattato II*, p.399-409. In delineating plans and elevations for linear and composite churches he uses ratios based in the circumference of the circle. Similar ratios are used to describe the relationships between various parts of the machines and their actions. For a more extensive discussion of Di Giorgio's proportions and church designs see: Lowic, Lawrence. "Francesco di Giorgio on the Design of Churches: The Use and Significance of Mathmatics in the Trattato." *Architectura; Zeitschriftfr Geschichte der Baukunst* 12 no.2 (1982), pp.151-163.

night, nor the ripening of fruits. Thus when our ancestors had seen this was so, they took their models from nature, and by imitating them were led on to divine facts, until they perfected the contrivances which are so serviceable in our life.[4]

In the Christian Middle Ages, this symbolism is taken up by Dante's *Divine Comedy* which contains machine imagery as well[5]. In this passage from *The Inferno,* the image of a windmill is used to describe the indescribable presence of the devil:

As when the thick autumnal mists exhale,
or when night draws down on our hemisphere,
A mill shows far away with turning sail,...
And I may with a giant more compare
than giants with those monstrous arms of his:
Consider now how huge must be the whole
Proportioned to the part of such a size.
If he once was fair as he now is foul,
And 'gainst his Maker dared his brows to raise,
fitly from him all streams of sorrow roll."[6]

Although Francesco Di Giorgio makes no specific mention of the theological dimension of the machines in his accompanying text, these precedents bear consideration in relation to his architectural. To begin, there are the religious origins of a few of the mechanical elements. The vertical axle windmill, as drawn by Taccola and copied by DiGiorgio, was one of the earliest to appear in Europe. European windmills before that time were made with a horizontal axle. Lynn White speculates that the many slaves from Tibet and other regions in the east brought the design from the monasteries, where the windmills were used exclusively for prayer.[7] Buddhists used the rotation of prayer cylinders powered by various sources to

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[4]Vitruvius.p.284,

[5]Hook, *Siena*. She notes that in Di Giorgio's time, recitations from the *Divine Comedy* were part of the celebrations of St. Catherine of Siena. p.124.

[6]Alighieri, Dante. *The Divine Comedy.* Translated by Laurence Binyon; annotated by C.H. Grandgent. New York: Penguin, 1977. Canto XXXIV, p. 182-183. "This section is believed to be the earliest Italian reference to a windmill" in the essay "Technology and Invention in the Middle Ages" from White, Lynn. *Medieval Religion and Technology.* Berkely: University of California Press, 1978. p.21.

[7]White, Lynn. *Medieval Religion and Technology.* p.47.

generate the recitation of meditative prayers. At around the same time as Taccola's windmill, other technological advances are made [with apparently eastern influence]: One developement is the use of fire to generate turbine rotation and the other is the ball and chain governor found in the sketchbook of Francesco di Giorgio.[8] While it is unlikely that either Di Giorgio's or his predecessor Taccola's interest in these machines was singularly devotional, it is interesting that the world view of both Eastern and Western cultures would include an emphasis on circular motion as a pathway to divine knowledge.

The possible theological implications of Francesco di Giorgio's machines are probably best illustrated by an analysis of his painting *The Coronation of The Virgin.* Done as an altarpiece for the monastery at Monte Olivetto in 1475, the painting depicts Mary's ascension into heaven. In the center of the painting, Mary kneels as Christ crowns her. Christ sits on a throne of cherubs, and is attended by four angels. They occupy a circular platform of winged putti heads. Supported by various levels of cherubs and angels tapering in towards the central axis as if drawn by centripetal force, the axis descends into a branch in the hand of St. Catherine of Siena and ascends into the churning presence of God the Father. As my hagiographic knowledge is limited, I have relied on Weller's identifications.[9] The kneeling figures in the foreground are St. Sebastian and St. Catherine of Siena. In the steps flanking the axis are St. Agnes, St. Dorothy, St. Ansanus bearing the shield of Siena, St. Stephen and St. Lawrence, with Saints Peter and Paul on either side in the top row of standing figures. Above them are the prophets and patriarchs with John the Baptist seated on the far left and King David on the right. Beyond them a diaphanous ring of cherubs encloses the esteemed audience.

In the dome of the sky, the portal to the heavens is circumscribed by another ring of winged putti heads. Ascending from that are a stack of seven rings. These are

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[8]Ibid, p.48-49.

[9]Weller, Alan Stuart. *Francesco Di Giorgio Martini 1439 -1501*. Chicago: The University of Chicago Press, 1943.pp.99-100.

Figure 47. Francesco Di Giorgio's *Coronation of the Virgin*. Reproduced from Carli, Enzo. *Sienese Painting*. London: Summerfield Press, 1983.

Figure 48. The heavens from *The Coronation of the Virgin.*

surmounted by another ring of figures - presumably angelic forms - in the center of which stands the *primum mobile*, blurred by the whirl of motion around him. Weller concludes that this is Di Giorgio's depiction of the nine heavenly spheres of Dante's *Paridiso*.[10] The lowest ring is designated by a circle, and can be read as the moon, and the next - assigned a female figure - is Venus. Early Medieval astronomers would include Mercury in this sphere as well, which would account for there being seven rings instead of eight beneath the *primum mobile*.[11] The ring above it has a circle representing the sun. The male figure in the subsequent ring represents Mars. The next sphere would be Jupiter, followed by Saturn - described by another male figure. The seventh sphere would be that of the stars. The eighth is the realm of the *primum mobile*. "At such a distance round the Point there whirled a ring of fire so swift it had surpassed the motion which most swiftly girds the world."[12] And the ring of figures beyond the ninth sphere, the Empyrean, described by Dante:

> In the figure of a circle it stretcheth on
> And out, so far that its circumference
> Would be too wide a girdle for the sun.
> All of it is one radiant effluence,
> Reflected downward from the First Moved Sphere,
> Whose virtue and energy proceedeth thence;...[13]

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[10]Ibid. p.101

[11]Ibid.. p.101

[12]Dante, Canto XXVIII,p.513.

[13]Ibid.. Canto XXX, p.523.

While not explicitly describing the orders of angels as they appear in the *Paradiso*, Di Giorgio does offer nine distinct representations of angels.[14] And the various levels of the holy audience might also imply the nine classes of souls, which Di Giorgio might have reduced to seven by leaving out the two which are within reach of the earth's shadow.[15]

The spheres of heaven, the ranks of angels, the classes of souls - a heavenly depiction that describes the Early Renaissance conception of the universe. Pre-Copernican man's central position has not yet been usurped by the sun, yet a developing understanding of the infinite in relation to the divine is apparent.[16] That God is the center of the heavenly spheres while being on the circumference of the sphere of the painting might be read as an attempt to actually represent the concept of an infinite sphere whose center is its circumference. As this painting is a representation of the Dantean universe, it is interesting to look at his allusion to this in the same Canto that describes the concentric spheres of heaven and the nine ranks of Angels. In Canto XXVIII, Beatrice attempts to help Dante reconcile the spheres of Heaven with those recognized corporally. She tells him:

> "If thou measure round the virtue drew,
> not round the seeming substance that thy sense
> Doth as a circle to thy mind construe,
> thou would'st perceieve a marvellous congruence
> Of great with more, and small with less, appear
> In each heaven, with its own Intelligence."[17]

In the fifteenth century Nicholas of Cusa, in his *De Docta Ignorantia*, describes this infinite sphere in detail with accompanying geometrical proofs of its encompassing nature of the infinite. Naming the sphere "the maximum" he describes it in

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[14]Weller . p.102.

[15]Ibid. p. 102.

[16]Koyre, Alexander. *From Closed World to Infinite Universe.* Baltimore, Johns Hopkins Press, 1957.

[17]Dante. Canto XXVIII,p.514.

Aristotelian terms. "It is the efficient Cause, since it is the center; it is the formal cause since it is the diameter; it is the final cause since it is the circumference."[18]

Dante uses the concepts of relative rest and motion to describe the heavens, while Cusanus speaks of sphere in the abstract terms of causation itself, but both authors describe the developing notions of the universe and the situation of the world through their understanding of Aristotelian physics. In *The Coronation of the Virgin* Francesco Di Giorgio paints the same understanding.

Figure 49. The "cog" supporting Christ and Mary.

The depiction of the space of the painting as a section through a sphere and the implied motion of the central platform and the *primum mobile* above it illustrate a particular understanding of Aristotle's physics. The Lord, on the perimeter of the dome of the heavens, acts as both the primary cause, and the final cause. As the first cause God, the unmoved mover of *Physics VIII* and *Metaphysics XII,* creates that rotating wind around his feet. It is the first and eternal motion that moves everything else in the universe. As the final cause, he terminates the axis of Mary's ascension: he is the final good that everything worthy moves towards. The painting is therefore an Aristotelian model of the universe, describing its motions and causes.

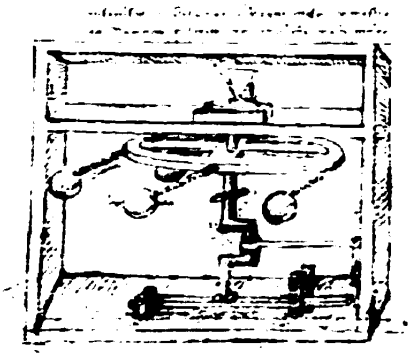

Figure 50. A machine from Di Giorgio's *Trattato I.* f33v TAV.62

It is revealing to compare the structure of the painting with Francesco Di Giorgio's drawings of machines, which are also considered on the Aristotelian model. The platform that supports Christ and Mary can be seen as a toothed gear rotating on an implied shaft that is the central axis of the painting. The rotation of the

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[18]Cusa. p.76

disk is enhanced by the imagined interaction of the supporting angels and the audience of saints and prophets that flank the "mechanism". The mechanistic structure of the painting can be extended to assume that Mary, as the intercession between earthly action and the divine, is the intersection of a crank and connecting rod . Translating the divine circular motion of the machine in the painting into other linear forces for the benefit of man, in his earthly realm.

Henry Adams, a medieval scholar in the late nineteenth and early twentieth century was inspired by the motivating force of the Virgin in the medieval and renaissance eras. He believed "It was the virgin who had raised up the cathedrals and caused poets to sing and philosophers to build structures of majestic thought." [19] Describing his impressions after a visit to the gallery of engines at the World Exhibition in Chicago in 1900 Adams likened the influence of the virgin to the newly invented dynamo. "...at Lourdes and at Chartres, as he knew by the record of work actually done and still before his eyes, was the highest energy ever known to man, the creator of four-fifths of his noblest art, exercising vastly more attraction over the human-mind than all the steam-engines and dynamos ever dreamed of."[20] One can then read the Virgin of Di Giorgio's painting as the generating force, whose power comes from her proximity to God, for prayers and moral action. The painting is a prayer machine, whose efficient cause is the Virgin, and whose final cause is salvation. Like the prayer machine of the painting, the machines of Francesco Di Giorgio's *Trattati* encourage the actions of man, actions that facilitate "the perfection of the house, fort and castle"[21] A perfection that is not possible without the combination of drawing and text to explain and show the concepts.

> Et ultimatamente, come nel principio è ditto, dato che alcuno nella fantasia avesse ordinato alcuno ragionevole edifizio o vero instrumento, volendo quello

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[19]Elizabeth Stevens in her introduction to Henry Adams poem "Prayer to the Virgin at Chartres" from *A Henry Adams Reader.* Garden City New York: Doublday and Anchor Books, 1958. pp.348.

[20]Adams, Henry. "The Dynamo and The Virgin" from *The Education of Henry Adams.* Boston: Houghton Miflin Co., 1974. pp.385.

[21]Francesco Di Giorgio. *Trattati II.* p.intro to book seven

> fare componare e fabbricare, non può senza il disegno esprimare e dichiarare el concetto suo; questa parte consequendo, non sarà difficile con questi pochi descritti principi venire a notizia di più vere conclusioni e ragionevolmente operare con l'aiuto del fattore del tutto da cui tutte le virtù sono concesse.[22]

Concepts, which as Di Giorgio concludes in the last lines of his Trattati, cannot be conceived without "the essential aid of God from whom all virtues are produced." Through architecture man approaches its final causes - the good of man and the honor of the Virgin and the Glory of God.

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[22]Trattato II, p.506.

Demonstration and Revelation

On the page Di Giorgio's machines are both *machina heroica* and a *machina admirabilis*.[1] They are machines to be admired because as they are drawn and described on the page they are invested with the forces and motions that facilitate their "working." And they are heroic because while based on the science of natural motion and physics, they can be elevated to a symbolic dimension representing the workings of the universe. The practical tangible world of water, food, and shelter, the wondrous, logical world of science and investigation, and the divine actions on the world itself are all demonstrated in the workings of Francesco Di Giorgio's machines. They communicate the complex nature of his world, not in spite of being unbuildable, but precisely because they cannot be fully instrumentalized. It is frozen on the page, set in their boxes, like precious jewels, that they have the potential to evidence so much, so far outside of their practical function. In the space between the text, the image and the imagination, Di Giorgio's machines can be constructed into multiple *fantasie* that reflect their varied relationships with the world - the world of the reader, the world of the architect. Once built, these possibilities, emphasized and celebrated by Di Giorgio, would recede, leaving the machine to be considered only in its ability to accomplish a singular task. Di Giorgio's devices would be silenced; no longer able to suggest concepts beyond the work they do.

Today, it is difficult to comprehend the value of a machine that cannot be realized. We cannot easily activate our devices in our imaginations. The molded plastic logic board of our computers, lacks the evidence of lived experience that is revealed by Di Giorgio's inert machinery. Of the three departments of architecture as set out by Vitruvius, the making of timepieces, the construction of machines, and

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[1] Frascari, Marco. "A Heroic and Admirable Machine: The Theater of the Architecture of Carlo Scarpa, Architetto Veneto." *Poetics Today* 10 vol.1 (Spring 1989) p.109. "...the relationship between building and machine is fundamental to a thoughtful architecture. In Italian the word *machina*, "machine" once indicated a fabbrica, "building".

the art of building, the first two are lost to us today. We have only the art of building in which to still invest with an adequate reflection of ourselves. In the limitations of architecture and in its power to mediate between the fixed and the infinite there lies the hope that "heroic and admirable machines" made, conceived and crafted, by man, can still demonstrate the world, our world.

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